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COST-BENEFIT AND FAILURE-CRITICALITY ANALYSES OF THE STANDARD AVIONICS INTEGRATED CONTROL SYSTEM (SAICS) CONCEPT

June 1981

Prepared for
AERONAUTICAL SYSTEMS DIVISION
DEPUTY FOR DEVELOPMENT PLANNING (ASD/XR)
AND DEPUTY FOR AVIONICS CONTROL (ASD/AX)
WRIGHT-PATTERSON AIR FORCE BASE
DAYTON, OHIO 45433
under Contract F04606-79-G-0082-S706

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ABSTRACT

This document reports on ARINC Research Corporation's eight-month investigation into the existing individual and integrated avionics cockpit controls of contemporary aircraft. Through failure-criticality and cost-benefit analyses, it examines the potential of a Standard Avionics Integrated Control System (SAICS) as a replacement for existing individual controls. The report provides information on existing individual cockpit avionics control mean times between failures (MTBFs), costs, weights, and sizes. It also provides MTBF, cost, space, and weight estimates for a unique integrated control, a standard avionics integrated control, and a manual back-up control panel for both.

The study addresses primarily hardware, not software, and places emphasis on avionics control rather than display. It is assumed that installation of a SAICS would begin in five candidate tactical aircraft some time after 1985.

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Prepared for

Aeronautical Systems Division
Deputy for Development Planning (ASD/XR)
and Deputy for Avionics Control (ASD/AX)
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under Contract F04606-79-G-0082-S706

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FOREWORD

This report was prepared by ARINC Research Corporation for the Aeronautical Systems Division's Deputy for Development Planning (ASD/XR) and Deputy for Avionics Control (ASD/AX) under Contract F04606-79-G-0082-S706. It presents the results of an eight-month investigation into the existing individual and integrated avionics cockpit controls of contemporary aircraft, and it examines the potential use of a Standard Avionics Integrated Control System (SAICS) as a replacement for existing and planned controls in five candidate tactical aircraft.

ARINC Research Corporation wishes to acknowledge the excellent cooperation received from the many engineers who participated in the investigation. Their names are listed in Appendix A. We particularly appreciate the support provided by the Sacramento ALC F-111F avionics equipment specialist, Mr. B.J. Rutledge.

ABSTRACT

This document reports on ARINC Research Corporation's eight-month investigation into the existing individual and integrated avionics cockpit controls of contemporary aircraft. Through failure-criticality and cost-benefit analyses, it examines the potential of a Standard Avionics Integrated Control System (SAICS) as a replacement for existing individual controls. The report provides information on existing individual cockpit avionics control mean times between failures (MTBFs), costs, weights, and sizes. It also provides MTBF, cost, space, and weight estimates for a unique integrated control, a standard avionics integrated control, and a manual back-up control panel for both.

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CONTENTS

CONTENTS (continued)

CONTENTS (continued)

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CHAPTER ONE

INTRODUCTION

1.1 SCOPE

This report presents the results of an eight-month investigation into existing individual and integrated avionics cockpit controls of current aircraft. It examines the potential of a Standard Avionics Integrated Control System (SAICS) as a replacement for existing individual controls. The objective of the study was to provide Air Force planners with the following:

- Information on the state of the art of cockpit controls
- A review of existing and planned avionics subsystems in five candidate tactical aircraft: F-4E, F-15A, F-16A, F-111F, and A-10A
- A determination as to which individual avionics control functions might prove suitable for integration
- A criticality-of-failure analysis relating individual and integrated cockpit control failures to the probability of mission failure
- A cost comparison relating the costs of installing, replacing, or removing individual and integrated controls in the five candidate aircraft

The report provides information on existing individual cockpit avionics control mean times between failures (MTBFs), costs, weights, and sizes. It also provides MTBF, cost, space, and weight estimates for a unique integrated control, a standard avionics integrated control, and a manual backup control panel for both.

The study addresses primarily hardware, not software, and places emphasis on avionics control rather than display. It is assumed that installation of a SAICS would begin in the candidate aircraft some time after 1985.

The report was prepared by ARINC Research Corporation for the Aeronautical Systems Division's Deputy for Development Planning (ASD/XR) and Deputy for Avionics Control (ASD/AX) under Contract F04606-79-G-0082-S706. This SAICS effort was part of a larger overall program regarding Packaging, Mounting, and Environmental (PME) Standards for avionics.

1.2 BACKGROUND

Over the past decade, aircraft operational requirements have become more demanding in response to the changing threat and the need to conduct missions in reduced visibility and marginal weather. To meet these more demanding requirements, the number of electronic systems on board an aircraft has been substantially increased. There has been a parallel increase in crew workload, cockpit space requirements, and total system weight. Fortunately, the rapid advance of digital technology has produced a new type of avionics system architecture with the potential for reducing system complexity, crew workload, and cockpit panel space requirements, and at the same time increasing configuration flexibility and mission capability.

The advances in integrated avionics architectures can be partly attributed to the introduction of the Military-Standard-1553 multiplexer bus. Another major contributor has been the rapid growth in the use of embedded computer systems and microprocessors, which have reduced avionics size, weight, and power requirements while easing cockpit workload by increasing processing speed and the quantity and quality of information available to aid decision-making.

An integrated system approach can accomplish the following:

- Minimize pilot workload by coordinating the interaction of related subsystems
- Minimize avionics weight and space through the use of a multiplex data bus and elimination of unnecessary duplicate components of separate subsystems
- Reduce logistic support costs by minimizing the number of line replaceable units (LRUs)
- Maximize system reliability through fault-tolerant design, achieved by careful system functional and hardware partitioning

The need for a detailed review of avionics cockpit controls, leading to a prototype development program for an Air Force standardized integrated control system, was highlighted at the first two Air Force Avionics Planning Conferences held during 1978, and the First Annual Armament and Avionics Planning Conference held in October 1979. At these conferences the development of a SAICS was proposed as a candidate for standardization to exploit technological advances in the areas of cockpit controls and displays. It was envisioned that a fully compatible MIL-STD-1553 SAICS would reduce pilot workload and minimize cockpit panel space and weight by concentrating most of the control functions in one control unit.

Of the various schemes suggested by the conferees for the integration of different functions and systems to increase the available panel space, SAICS appears to provide the smallest economic and technological risk, to have the least effect on air-crew training, and to provide best for increased air-crew efficiency. SAICS is an integration scheme that provides for the interface of standard avionics equipment (e.g., ARC-164 UHF radio, ARC-186 VHF/UHF radio, ARC-190 HF radio, F^3INS, ARN-127 VOR/ILS, ARN-118 TACAN, APX-101 IFF, KY-58 speech security device) on a MIL-STD-1553 multiplex bus. This integration scheme permits most systems on the bus to be controlled from a single control and display unit.

At the time of publication of this report, the future of the SAICS is still uncertain. However, several Air Force programs are in progress to plan for and produce an integrated control head similar to that envisioned in the SAICS concept.

1.3 TASK DEFINITION AND APPROACH

The tasks assigned to ARINC Research Corporation by the statement of work were to analyze SAICS concepts and provide ASD/AXA/XRS with reliability and cost analyses concerning existing and future individual and integrated cockpit controls. Three tasks were defined, as discussed in the following subsections.

1.3.1 Task 1: Determine Trial Avionics Functional Groupings

In Task 1 we selected specific groups of avionics that showed the potential for benefiting from integration of their control and display functions in terms of mission performance, pilot workload reduction, and cockpit panel or console space reduction.

Before selecting the trial functional groupings, we reviewed technical documentation and visited several manufacturers and Government organizations to determine the types of integrated controls and displays now used in aircraft such as the F-15, F-16, and F-18, and also planned for new Government and commercial aircraft, such as the Boeing 757 and 767. Fifteen past, present, and future Government and commercial programs were reviewed to identify and assess the state of the art in cockpit integrated controls.

1.3.2 Task 2: Failure Criticality Analysis

Each of the SAICS functional groupings developed in Task 1 were evaluated to determine the impact of failures on mission performance. Representative air/air (A/A) and air/ground (A/G) European mission scenarios for the candidate aircraft were developed to determine typical times for the phases of a mission. Avionics functions hypothesized to be included in the SAICS were examined to determine the criticality of a failure during the primary mission phases. The possibility of a back-up mode of operation not affected by the failure mode was also investigated.

1.3.3 Task 3: Cost-Benefit Analysis

We used three approaches to perform a cost-benefit analysis. The first approach was based on the current practice of using individual control and display devices for each avionics function. This approach recognized that in some aircraft types there is little or no potential for incorporating new avionics functions without extensive redesign and relocation of present control and display devices in the existing cockpit console/panel space. It also recognized that mission capability might be degraded in some instances because of the greater demands on human performance in controlling new avionics functions during the mission.

The second approach was based on the use of control and display integrations where one or more groups of avionics functions were uniquely integrated for a given type of aircraft and mission. In this approach, it was assumed that no software or hardware interface standardization was mandated for this type of integrated control and display subsystem.

The third approach was based on the use of a SAICS for all candidate aircraft. Two levels of complexity were evaluated. The simplest integration covered a single group of closely related functions, such as those required for communications, radio navigation, landing, and identification subsystems. The second level of integration included two major groups of avionics functions. Both levels included provisions for growth in the hardware and software areas without repackaging of the equipment.

1.3.4 AVSTALL Cost Model

The ARINC Research avionics installation (AVSTALL) cost model was used to estimate the relative costs of installing and relocating control panels and cockpit LRUs for each of the trial functional groupings. For the three approaches, costs and weights of existing controls were determined and estimates were made for future individual and integrated controls. These were used to compare costs of the first alternative (current practices) with the second and third alternatives (integrated concepts) for both non-standard cockpit controls and a SAICS CDU.

1.4 REPORT ORGANIZATION

Chapter Two summarizes a sample of past, present, and future integrated control system programs, including a review of the major integrated avionics architecture technology initiatives by each military service.

Chapter Three reviews the existing avionics in the candidate aircraft and establishes four trial functional groupings used as the basis for the failure-criticality and cost-benefit analyses. It also provides a conceptual layout of the F-111F after its existing individual controls are removed and replaced with integrated controls.

Chapter Four presents the failure-criticality analyses, and Chapter Five presents the cost-benefits analyses. Chapter Six presents our candidate SAICS avionics functional groupings; and Chapter Seven is a summary of findings, conclusions, and recommendations.

Appendix A lists the personnel and organizations contacted during the study.

Appendix B presents the summaries of the mission-profile investigations and the mission-performance computer runs for the five candidate aircraft. It also describes the methodology and equations used to calculate the probability of mission failure for individual and integrated controls.

Appendix C describes the ARINC Research AVSTALL cost model and how it was used for the cost comparisons.

CHAPTER TWO

REVIEW OF INTEGRATED CONTROL SYSTEM PROGRAMS

2.1 NATURE AND PURPOSE OF REVIEW

A SAICS draft specification* was developed in 1979 (by the Aeronautical Systems Division) in anticipation of an FY 1981 program go-ahead. The system envisioned at that time could provide control and display for standard airborne communications, navigation, identification (CNI) equipments. It included provisions for growth to control up to 14 subsystems to handle other avionics subsystems planned for future new and retrofit installations. This specification identified eight standard subsystems to be controlled by using a MIL-STD-1553 bus and four major components to be designed for modularity.

This chapter reviews briefly a sample of past, present, and future integrated control system efforts similar to that being proposed for the SAICS program. The primary emphasis of this review is on the control of avionics subsystems rather than on their display functions. The review covers a representative cross section of current efforts to assist the reader in our subsequent analyses.

2.2 PAST PROGRAMS

2.2.1 F-4E ASQ-19B Integrated Electronic Central

The ASQ-19B system, now more than 10 years old, was developed for use in the dual-seat F-4 series aircraft. One of the first control units produced that contained a computer (core memory), this integrated electronic central combined the equipment necessary to control the functions of communications, navigation, and identification. The five major subsystem components were the UHF communications transceiver, the TACAN receiver-transmitter (RT), the pulse decoder, the auxiliary receiver automatic direction finder (ADF) power supply, and the IFF coder RT. Intercommunications equipment, antennas, controls, indicators, and a filter completed the system complement.

**Military Specification for Control-Display Group OK-395/ASQ*, 30 October 1979.

2.2.1.1 Control

The AN/ASQ-19B used two separate controls in each F-4E cockpit. Control of the TACAN and ADF navigation functions, including switching to either fore or aft cockpit, frequency selection, and audio gain control was provided by radio set control C-6684/ASQ.

Identification functions of the AN/ASQ-19B were provided by the IFF coder RT. Cockpit controls for the identification functions were provided by the APX transponder set controls.

Facilities were also provided to combine and amplify audio-frequency signals from the UHF, TACAN, and auxiliary receivers. The AN/ASQ-19B system used a pair of intercommunications stations to process additional radio inputs and provide facilities for intercockpit and cockpit-to-ground-crew communications.

2.2.1.2 Display

The selected UHF communication preset channel was displayed on remote UHF frequency channel indicators located on the instrument panels in both cockpits. The UHF radio transceiver was compatible with secure communications equipment.

The TACAN RT and pulse decoder units provided bearing-to and -from information, deviation indications, and distance information -- all presented on the aircraft's horizontal situation indicator. The ADF function used the auxiliary UHF receiver and two additional modules for ADF signal reception and antenna control. The UHF communications transceiver also could be used for ADF reception.

2.2.2 UH-1 Integrated Avionics Control System (IACS)

In 1972 the U.S. Army Avionics R&D Activity (AVRADA) initiated an internal program with the goal of developing a simple, low-cost integrated cockpit control/display system for use in Army helicopters. The following program guidelines were established at that time:

- To provide control of the avionics equipment through a single integrated panel
- To reduce air-crew workload
- To increase avionics configuration flexibility

In 1974 an experimental model was designed, built, and evaluated. This in-house program led to the development of an integrated avionics control system specification in 1976. During the IACS program it was determined that more than 200 square inches of cockpit space would be saved (41 needed rather than 257) if a single integrated control head replaced the existing CNI individual controls in the UH-1E helicopter.

Two contracts called for the delivery of eight fully qualified systems in October 1978. Formal flight and operational tests were subsequently held at Fort Rucker, Alabama.

The basic IACS, nomenclatured by the Army as the AN/ASQ-166, consisted of five units:

- Primary control and display unit (PCU)
- Secondary control and display unit (SCU)
- Status panel
- Central control unit (CCU) 1
- Central control unit (CCU) 2

Figure 2-1 is a block diagram of a typical IACS interconnection. The primary control unit performed the following functions:

- Mode and display controls and keyboard entry of data
- Mode and frequency information and other data display on its front panel

The PCU was designed to control up to 10 avionics equipments, remotely located in the aircraft avionics compartment. Control of such actions as selecting preset frequencies, tuning to new frequencies, and using secure voice (KY-crypto) was accomplished through the primary control front panel, which had the following modes of operation:

- IFF
- COMM
- NAV
- Status
- Index

Dedicated switches were retained for back-up of important functions such as recovery of last frequency, selection of guard frequency, and zeroizing of sensitive information.

The secondary control unit provided a minimum capability for emergency situations. The specification required it to control one FM and one AM radio and an automatic direction finder. This secondary unit was envisioned for use by each operator in cockpits for which space or funding did not permit a primary panel. The primary and secondary control units were to be mounted either in the center console for a side-by-side helicopter or in the side consoles for a helicopter with a tandem seating arrangement.

The status panel was a small, lightweight one-line display that provided frequency and mode status information about the transmitting radio. It

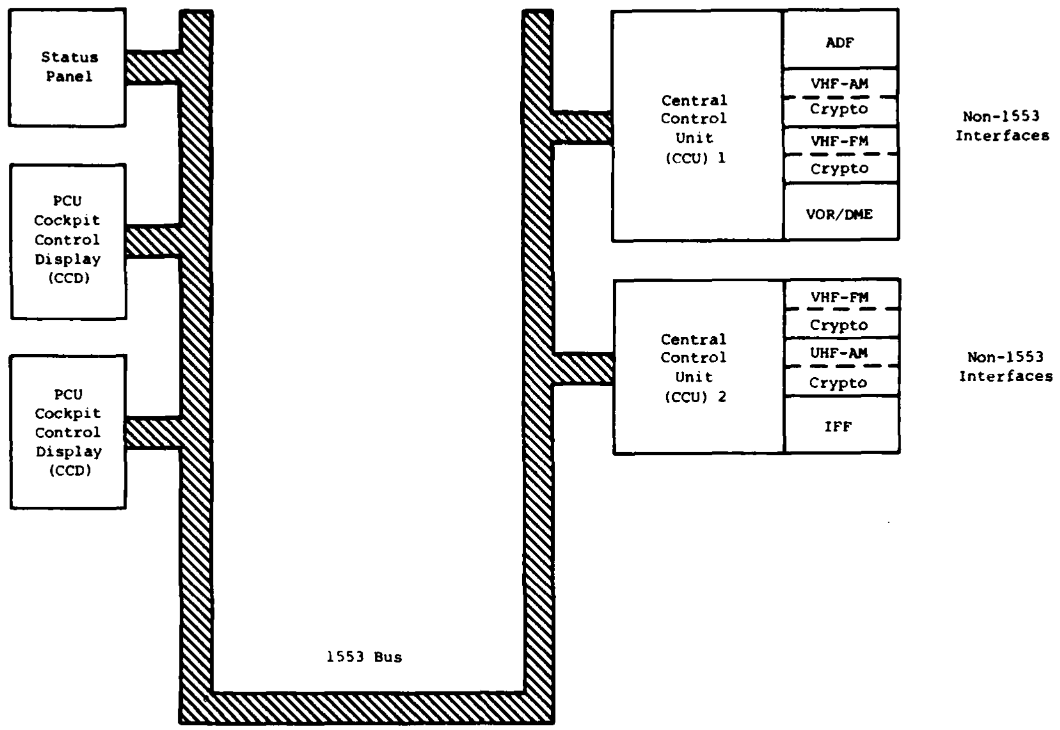


Figure 2-1. INTEGRATED AVIONICS CONTROL SYSTEM, AN/ASQ-166

was envisioned that the status panel would be installed as a head-up display near the brow of the instrument panel.

The intra-IACS connections were made through the use of a MIL-STD-1553A digital data bus. The choice of a digital multiplex bus over conventional hard wiring as the means of data exchange between the IACS and the controlled CNI equipments was in keeping with the overall goal of reducing aircraft complexity. Less wire and fewer connectors were required, with the attendant weight saving, reliability improvement, and simpler wire routing in the aircraft. Digital transmission techniques provide a higher data capacity, self-check on each transmission, and reduced susceptibility to electromagnetic interference.

The central control units provided a means of interfacing the IACS cockpit elements (primary control, secondary control, and status panel) with the controlled CNI subsystems. For the originally planned initial deployment of the system in the period 1982 through 1986, all subsystem equipments would be controlled through the two central control units. However, beyond that period, new subsystem equipments would be designed to interface directly with the data bus. The CCU would also provide the function of bus control for stand-alone operation. However, the IACS would be capable of operating as part of a larger bus system or in a dynamic (shared) bus control mode.

Although the IACS program achieved all of its goals, it never led to a production program. The system was fully qualified to MIL-E-5400 and demonstrated a 2,000-hour MTBF in accordance with MIL-STD-781B. Toward the end of the program, doppler (ASN-128) control was added to the system by changing the CCU software and adding a new I/O card. This change would have increased the overall production costs by approximately $500, but the overall system cost would still have been within the $22,500 goal.

The IACS concept thus proven is the forerunner of many of the commercial and Government programs either currently in production or being proposed.

2.2.3 USCG HC-130H CMS-80C System

During the IACS program, one of the competitors developed and produced avionics units similar to IACS that were subsequently delivered (in 1978) as a cockpit management system (CMS-80C) for four Coast Guard HC-130H aircraft. This system is a stand-alone COMM/NAV tuning system using dual 1553 multiplexer buses.

The CMS-80C consists of three cockpit control display (CCD) units, two system coupler computer (SCC) units similar to the CCU in the IACS program, and two remote readout units (RRUs) similar to the IACS status panels. It integrates the control of communications, VOR, TACAN, and IFF systems in a single unit. Figure 2-2 shows the CMS-80C interface with controlled avionics and typical locations of the CMS-80C equipment.

2.3 PRESENT PRODUCTION PROGRAMS

2.3.1 USCG HU-25A Flight Management System

In 1978 the U.S. Coast Guard also began work on integrating an advanced version of the HC-130H system into 41 of their medium-range surveillance (MRS) Falcon Jet aircraft.

The system (Figure 2-3) is designed around both a MIL-STD-1553-based CMS-80 system and a MIL-STD-1553-based RNAV subsystem, both of which share bus control through dynamic allocation. The equipment was designed to accommodate operation from remote terminal to remote terminal units as well as the basic (command response) remote terminal mode. The system has been flight-tested and awaits FAA certification. System computer features are as follows:

- System Coupler Computer
  - COMM/NAV Radio Tuning, Control, and Display

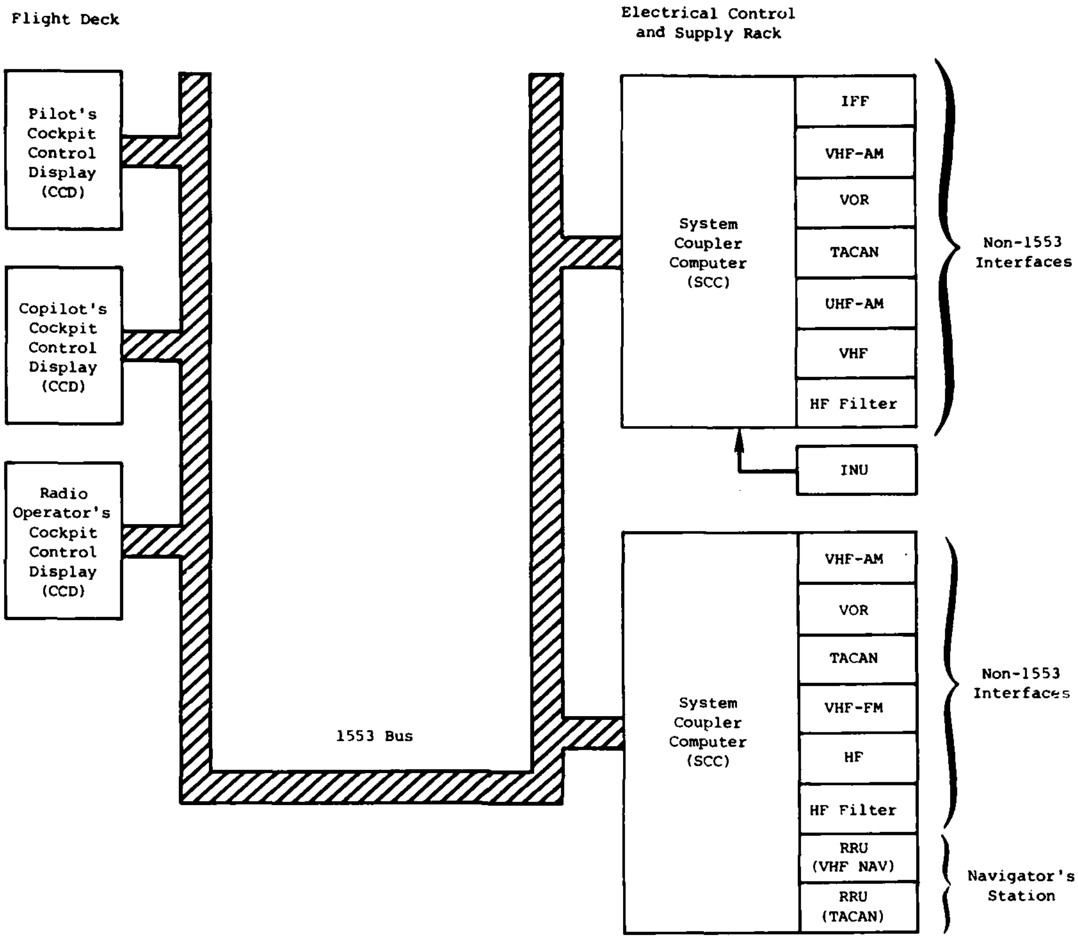


Figure 2-2. HC-130H COCKPIT MANAGEMENT SYSTEM

- •• Radar Data Display
- •• Bus Controller

- Mission Computer
  - •• Digital Filtering
  - •• Three-Axis Navigation Computation
  - •• Sensor Management
  - •• Fuel Management and Display
  - •• Radar Data Conversion and Management
  - •• Performance Management
  - •• Data Base Management

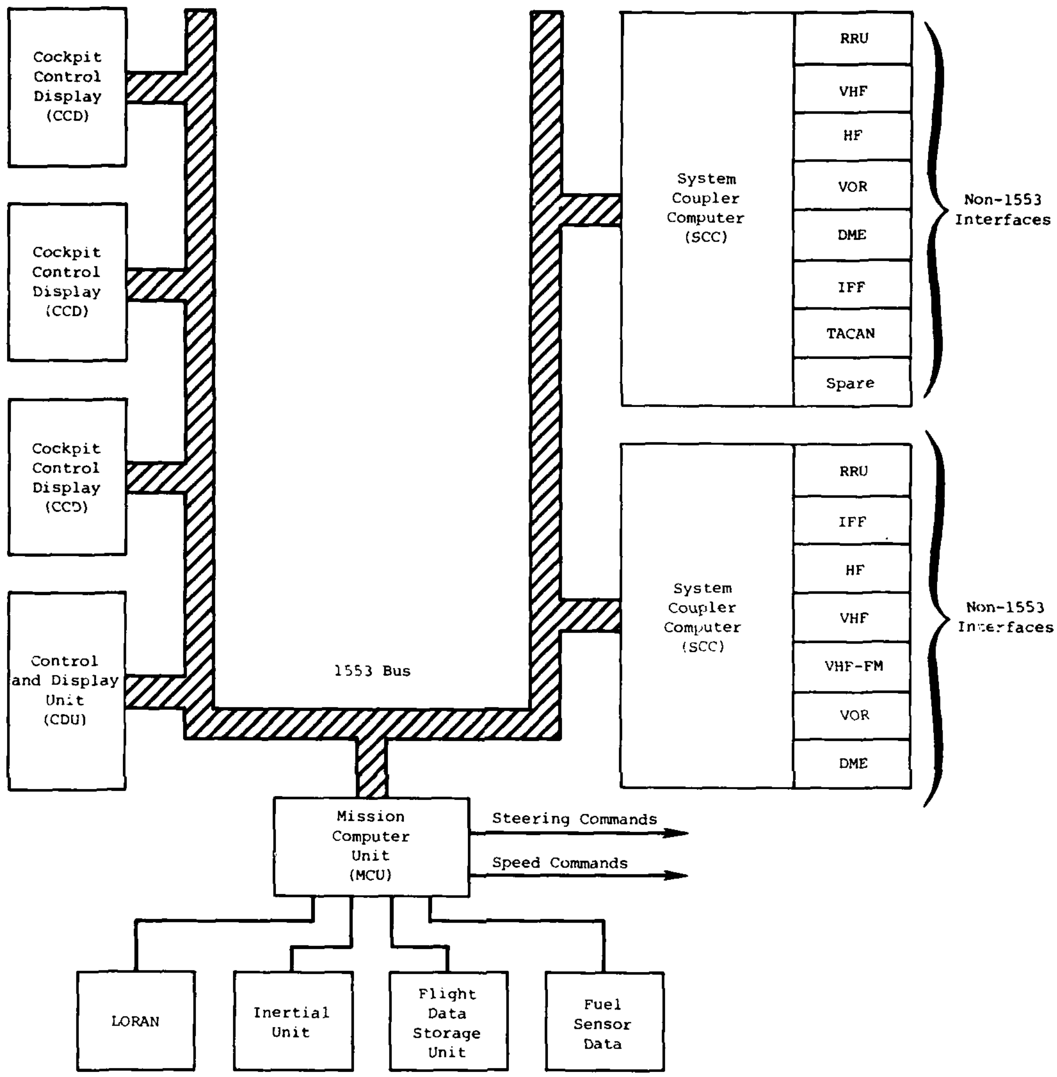


Figure 2-3. USCG MEDIUM RANGE SEARCH (MRS) AIRCRAFT

- •• Three-Axis Steering Commands
- •• Bus Controller

2.3.2 USCG HH-65A Flight Management System

One of the most recent advances in integrated avionics control is the development of the avionics suite for 90 Coast Guard HH-65A short-range recovery (SRR) helicopters. As shown in Figure 2-4, the SRR MIL-STD-1553B bus system represents one of the most sophisticated SAICS-type bus system

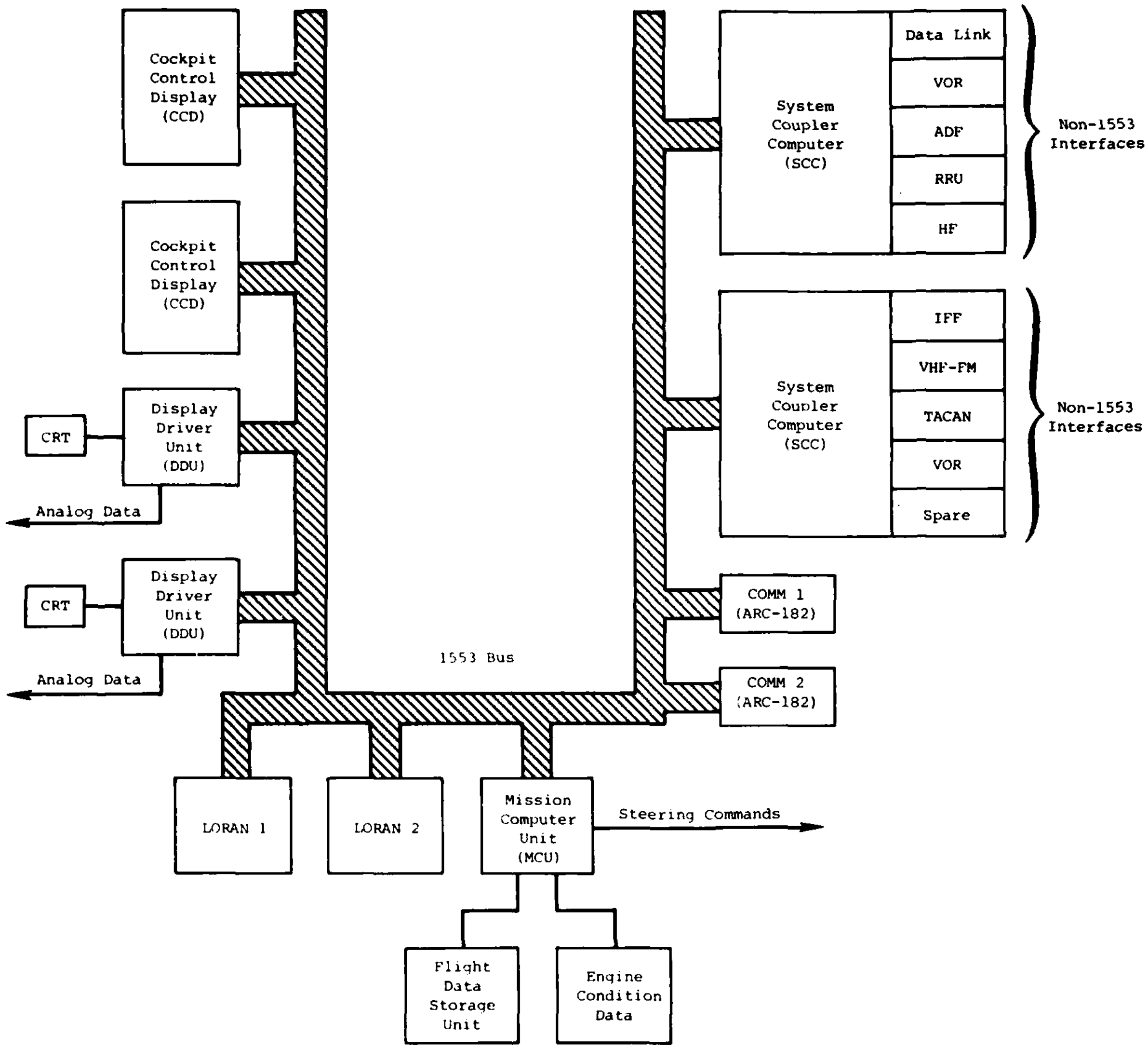


Figure 2-4. USCG SHORT RANGE RECOVERY (SRR) HELICOPTER

architectures. Additional multiplex units used in this configuration over the MRS suite include two horizontal situation video display (HSVD) drivers, two LORAN receivers, and two ARC-182 UHF/VHF communications radios.

The avionics system functions include the following:

- System Coupler Computer
  - •• CNI Tuning and Control
  - •• COMM/NAV Display Overlay and Control

- Data Link Management
- Back-Up Navigation Raw Data Display
- Primary Bus Controller
- Avionics System Self-Test and Fault Capability
- BIT Initiation
- Checklist

- Mission Computer
  - Bus Controller for Map and Navigation Data Central
  - Data Base Management
  - Digital Filtering
  - Automatic Steering Commands
  - Navigation and Fuel Management
  - Special Maneuvers Computation
  - Engine Condition Monitoring, Reporting, and Recording
  - Tactical Map Management

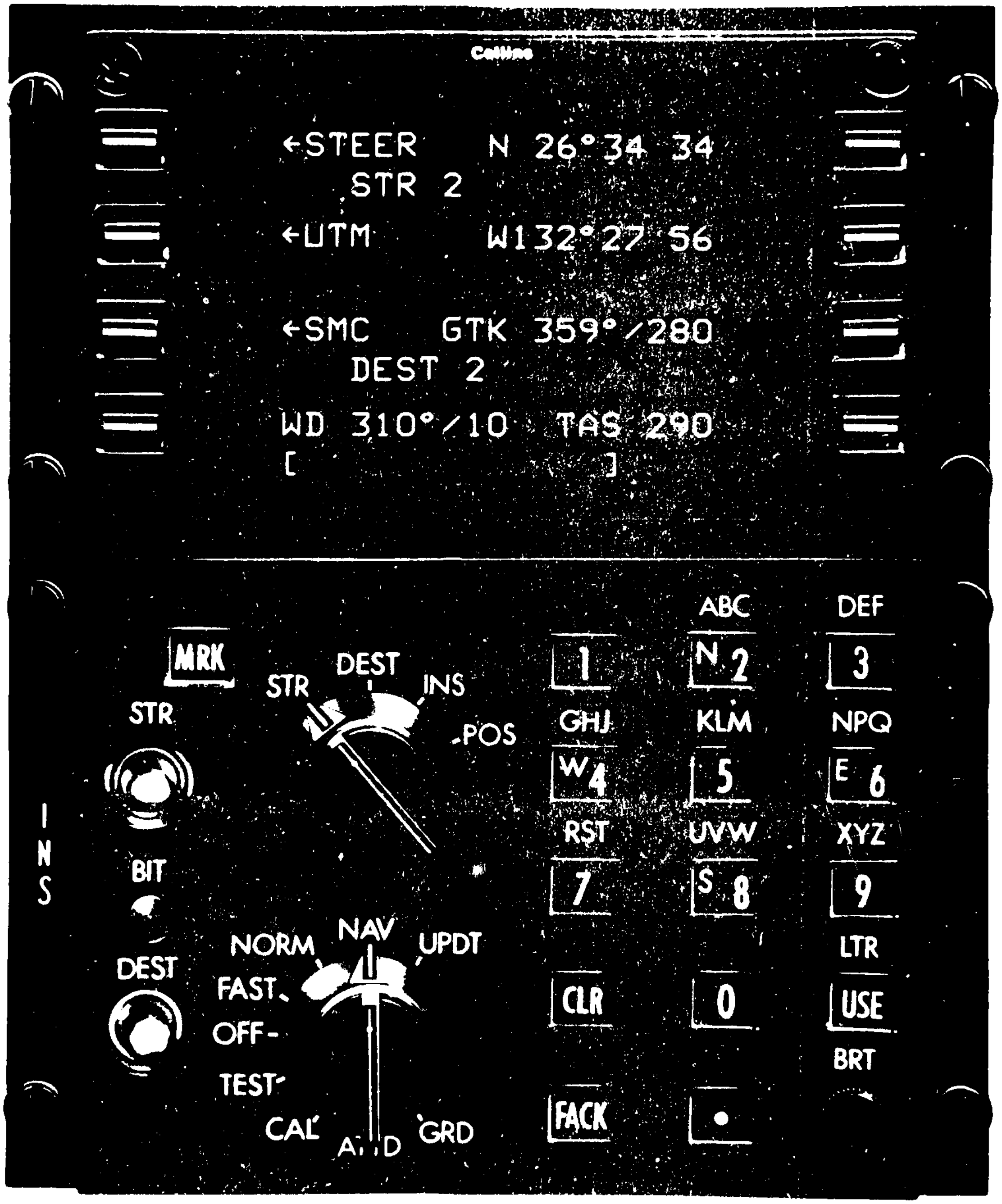
The system is planned to be operational in the spring of 1982, following FAA certification.

2.3.3 A-10 F^3INS Control and Display Unit

In June 1980 the Air Force awarded a 64-month contract to deliver specialized versions of the CMS-80 control and display unit for use with the A-10 F^3INS. The contract calls for delivery of 263 units, with options for up to 1,163. A pre-production model of the control head has undergone checkout and testing at ASD's 1553 Systems Engineering Avionics Facility (SEAFAC), and unit delivery for A-10 production aircraft will begin in May 1981. Present plans are to retrofit more than 600 A-10s with this CDU.

The F^3INS CDU (Figure 2-5) is designed to aid the pilot during close-air-support missions by rapid recall of various pages of data. It also performs other functions (such as system-level test). The pilot modifies or updates the information stored in the control head microprocessor by using two rotating dials and a keyboard. Navigation waypoints and steer-points can be preset into the CDU prior to takeoff and called up as needed by the pilot through touch control during the mission.

This 10-pound control head is the first unit of those discussed that contains a microprocessor module (24K erasable programmable read-only memory [EPROM]). The latest contract option for 233 units (exercised in March 1981) brought the price of the control head down from $13,000 to $9,080.



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DEST 2
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CLR
0
USE
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FACK

Figure 2- [illegible]

The approximate memory allocation (in Kbytes) for the control head functions is as follows:

INU Control	12.5
System-Level Test	1.0
Mission Data (for waypoints)	4.8
Elevation Information to pod	.5
Calculator	2.3
Scratch Pad	.4
Total	21.5

The software for the microprocessor is coded in the PLM-80 higher-order language (HOL).

2.3.4 F-15 Integrated Communications Control Panel

The F-15 digital integrated communications control panel (ICCP), C-9011/ARA, controls the No. 2 UHF RT, UHF auxiliary communications receiver, KY-28 speech security unit, ADF set, and intercommunications system (ICS). Auxiliary radio frequencies are separately controlled by using either the manual frequency selectors or a channel control that selects preset frequencies. Twenty preset UHF RT or auxiliary frequencies are stored in a nonvolatile read-write memory. A three-position toggle switch labeled ADF selects the UHF or ADF mode of operation. A three-position mechanical latching switch labeled CIPHER selects the KY-28 mode of operation. The ICS volume control and the auxiliary radio ON/OFF and VOLUME controls are also located on the front panel. Other controls located on the ICCP panel are a two-position toggle communications guard receiver switch, a spring-loaded KY-28 zeroize switch, the TEWS* CAUTION volume control, the WEAPON volume control, the LAUNCH tone volume control and push-to-disable switch, a three-position toggle antenna selector switch, and a pushbutton switch labeled CHAN SET for presetting the AUX and COMM frequencies.

An audio section contains a tone-generator circuit card assembly that generates four audio tones during unsafe landing conditions; these tones are applied through a mixer-amplifier to the pilot headset when activated by an external signal.

Controls for the main (No. 1) UHF radio and the IFF code selection (mode 3/A) are located on the HUD control panel, as well as selection modes for HAVE QUICK. The memory control for automatic tuning of UHF No. 1 is located in the ICCP. The two-seat F-15 has a second ICCP in the rear.

In June 1981 a new ICCP is to be installed in the F-15. This ICCP will have increased built-in test (BIT), the capability to continue controlling two radios (two UHF, or one UHF and one VHF), and control for

*Tactical Electronic Warfare System.

the JTIDS network. The single voice engine warning provided by the existing ICCP will be expanded to provide 10 voice warnings concerning the nature of the problem (e.g., "low fuel"). The modularized memory will be entirely solid state (2 Kbyte ROM, 128 Kbyte RAM, and five 32 Kbyte EPROM modules for voice warning). Average cost for this new ICCP (150 units for production aircraft, 559 to be retrofitted) is approximately $26,000 not including support equipment or R&D.

2.3.5 F/A-18 Communications System Control Set

The F/A-18 aircraft is the first modern tactical aircraft to utilize an on-board dedicated computer to control its communication, navigation, and identification avionics subsystems. This communication system control (CSC) set is the total interface between the aircraft's two AN/AYK-14(V) mission computers (MCs), the pilot-operated up-front control (UFC) panel, and the 17 CNI subsystems. The CSC provides operator and computer control of these systems and the transfer of data.

The F/A-18 CSC provides the intelligence and power to the UFC panel and, in terms of energy management, powers up or down those CNI subsystems as required by the pilot through the UFC panel. Operations in the CSC involve conversion and storage and the transfer of digital, analog, synchro, and discrete data.

The doubly redundant MIL-STD-1553A multiplex connections from the CSC to the MCs provide ports for flow of information and control between the MC and the CSC for the CNI equipment. Flow of control can be only from the MC to the CSC. Information on the alphanumeric display of the UFC panel (scratchpad and options) also flows from the MC to the CSC. The information that flows from the CSC to the MC consists of equipment status, received data, and operating options of equipment. BIT commands and BIT status also flow through the bus. To accomplish this requirement, the CSC contains a fast microprocessor, which controls and processes the required data.

2.3.6 Boeing 757 and 767 and Airbus A310 Flight Management Computer System (FMCS)*

The FMCS represents the most advanced commercial application of an integrated control system to date. For this reason, more detailed information is provided for it than for the other systems reviewed in this chapter. The two FMCS units -- a control display unit (CDU), and a flight management computer (FMC) designed to ARINC Characteristic 702 -- handle the basic tasks of performance management, navigation, guidance, and related display functions.

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*Information primarily extracted from October 1979 Sperry Flight Systems paper presented by Larry J. Bowe at the 1979 ATA Engineering and Management Forum, 1-2 November 1979.

2.3.6.1 Performance Management

The performance management function comprises full flight-regime control of the airplane vertical and speed/thrust axes within the constraints imposed by the flight plan or by Air Traffic Control (ATC). Computations and predictions are conducted for each flight phase, as well as along the whole flight profile. Variations on each flight phase, such as maximum rate climb, maximum angle climb, or long-range cruise, may be commanded by the pilot through the CDU.

Performance planning or look-ahead prediction may also be accomplished at any time through the CDU. The pilot may interrogate or change any function of each flight phase, and the resulting cost impact over the whole flight (as compared with the computed economy profile) will be displayed on the CDU. In the cruise segment, the flight profile is optimized to provide step-climb advisories based on predetermined altitude increments. Turbulence-penetration and engine-out data and advisories are also provided on demand. Cabin repressurization restrictions are accommodated in descent computations. Inputs for the performance management function are provided from the air data computer system, inertial reference system (IRS), fuel flow and totalizer, thrust management computer, and mode control panel. Airplane and engine data are stored within the FMC, and pilot initialization inputs are entered through the CDU.

2.3.6.2 Navigation Functions

The navigation function of the FMCS uses position and velocity inputs from the IRS, DME slant range, and VOR bearing, optimally mixed to compute lateral position. Air data computer and IRS inputs provide for vertical-position estimation. A navigation-mode hierarchy is established, with the IRS position updated by DME-to-DME fixing as the senior mode, degrading to single collocated VOR/DME fixing when qualifying DME-to-DME geometry is not attainable. When the aircraft is out of range of adequate radio coverage, the combined triple-IRS position inputs are used. The FMC performs the frequency-management and autotune functions to control VOR and DME frequency selection.

2.3.6.3 Guidance Functions

Lateral guidance is provided with respect to a flight plan that is activated by selecting one of two flight plans that may be assembled in the FMC. Flight plans may be constructed by the pilot on a waypoint-to-waypoint basis through the CDU or assembled by selection of terminal-area procedures and en-route segments from bulk navigation data stored within the system, or by selection of a pre-assembled company route stored in bulk data according to airline option. Provision is made for entry or modification of a flight-plan or other data by means of a data link such as the ARINC communications addressing and reporting system (ACARS). A design intention is that all flight-plan and other related data be entered and displayed on the CDU in accepted ATC terminology.

The FMCS provides lateral and vertical guidance in the terminal area, and it can be used to set up and intercept an ILS approach or fly a non-precision approach.

2.3.6.4 FMC

The FMC is housed in an ARINC 600 8-Modular Concept Unit (MCU) chassis that provides single-sided access to all shop-replaceable units (SRUs) and chassis components. Within the chassis, the subassemblies are arranged to minimize thermal-path lengths for greater cooling and high reliability, and also to reduce electromagnetic interference (EMI) effects. With the exception of the processor card, which is double-width, all circuit cards are of the same size and construction. The FMC weighs less than 32 pounds and dissipates approximately 100 watts.

The FMC main operational solid-state memory contains 64K of random access memory (RAM) and 128K of read-only memory (ROM) to accommodate future growth. The operational program is read into RAM in segments from a disc memory under the command of the software executive.

The high-capacity 256K disc memory is rugged, reliable, and compact. A capacity of slightly more than four million bits was selected to satisfy all present and projected requirements. The memory disc measures approximately 170 cubic inches and weighs less than 6 pounds. It is identical to the disc used in the F/A-18 radar.

2.3.6.5 *CDU*

The heart of the flight management computer system, from a pilot's viewpoint, is the control display unit (CDU). The CDU is designed to give the pilot complete and positive control of the FMCS.

The panel-mounted CDU has a cathode-ray-tube (CRT) display with six addressable data lines and associated header, label, and scratchpad lines. The lower faceplate contains 15 function keys, a full dedicated alphanumeric keyboard, and four status annunciators.

The CDU consists of three main components -- a control module, a CRT module, and a keyboard assembly -- combined to form a lightweight and rugged unit that is 9 inches high by 5.75 inches wide. The CDU weighs 18 pounds and dissipates less than 70 watts.

The CRT module contains CRT circuitry, deflection amplifiers, phosphor protection circuitry, and the high-voltage power supply. The control module contains the digital logic, control circuitry, and low-voltage power supply.

The 8085 microprocessor used in the CDU is a new-generation, 8-bit CPU with an instruction set that is 100 percent compatible with the 8080 microprocessor but provides a significantly higher level of integration. High-density programmable ROM (PROM) is used for the operational program of the CDU, and RAM is used for the display data and scratchpad.

The CRT and electronics provide a usable screen size 4.11 inches wide by 3.28 inches high to provide a 14-line 24-character alphanumeric display. The characters are stroke-written at a flicker-free refresh rate of 60 Hz.

More than 95 percent of the FMCS software is written in PASCAL, a higher-order computer language relatively new to commercial avionics.

2.3.6.6 FMCS Installation

A baseline FMCS installation for the Boeing 757 and 767 and Airbus A310 aircraft includes a pair of computers and control units for the captain and the copilot. Each FMC is linked to its own CDU, with provisions for data transfer between the two systems. A third CDU may be installed at the flight engineer's panel for call-up of performance data without interfering with other displays. A digital adapter switching unit (DASU) is available to interface the ARINC 429 bus with noncompatible avionics subsystems.

The system can accommodate 36 ARINC 429 serial digital inputs and provide nine ARINC-429 serial digital outputs. Potential growth features include 4-D (position, altitude, time) navigation, ARINC communications addressing and reporting, NAVSTAR global positioning control, VLF-Omega control, microwave landing system (MLS) control, frequency scanning for DME, on-board wind shear detection, and adaptive aircraft performance to access present performance as compared with models stored in the computer.

2.3.7 L1011 Fault-Isolation Data-Display System

The L1011 aircraft fault-isolation data-display system (FIDDS) is one of the first modern on-board aircraft maintenance sensor systems performing the following:

- Comprehensive LRU and continuous self-test
- System-level monitoring and fault isolation
- Continuous interface monitoring
- Nonvolatile fault-data storage

It provides for fault isolation and verification testing through the extensive use of fully automatic and semiautomatic interactive techniques. Consisting of a CDU (similar to those discussed earlier) and computer, the FIDDS receives, stores, and displays data supplied by other avionics subsystems. Capable of receiving, storing, and formatting for display up to 160 faults, it is used by both the flight crew and ground maintenance personnel. The fault is automatically stored by flight segment and time in the 6K computer memory (nonvolatile). The FIDDS also provides cockpit warning with up to six annunciators, as necessary.

2.4 FUTURE PROGRAMS

2.4.1 KC-135 Modification Program

Currently four approved (or soon to be approved) modifications are planned for the KC-135:

- HF radio
- Fuel savings advisory system (FSAS)
- VHF radio
- UHF/VHF/HF secure voice equipment

The FSAS requirement is the basis for all of the future KC-135 updates. This first modification program, to be managed by the Oklahoma City Air Logistics Center (OCALC), will provide for installation of the FSAS.

To implement all modification programs successfully, additional cockpit space or an integrated control system is required. Modification planners have designed a new cockpit layout. The new layout will be validated by SAC crews, and the equipment design requirements and growth flexibility will be based on the engineering work accomplished at ASD under the overall KC-135 Avionics Modernization Program.

The equipments to be procured and installed under one contract are as follows:

- FSAS computer
- Air data transducer
- CDU
- Bus controller/interface unit
- Miniaturized fuel panel

The CDU will act as an integrated control panel for both the existing INS and the new FSAS computer via a MIL-STD-1553B data bus. The bus controller/interface unit will provide bus control and interface of the INS to the data bus, as well as provisions for housing future interface modules for additional subsystems. The miniaturized fuel panel will have the capability for built-in-test, redundancy, and center-of-gravity corrections for enhanced fuel savings; but it will not be tied to the bus.

2.4.2 H-X Avionics Trade-Off Study

The October 1978 (updated December 1979) H-X Avionics Trade-Off Study* was intended to demonstrate the feasibility of integrating an avionics suite into the H-60 helicopter (as a replacement for the aging H-3),

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**H-X Night/Adverse-Weather Combat Rescue System Avionics Trade-Off Study*, ASD Study Team, October 1978.

to achieve a night and adverse weather rescue capability. In performing this study, the team members developed eight avionics screening factors: performance, cost, reliability, producibility, air vehicle compatibility, maintainability, survivability, and flexibility/commonality.

The results of the study show that incorporating a night and adverse weather combat rescue capability in the H-60 is practical. The study team arrived at this conclusion by defining a representative baseline avionics suite that meets all MAC requirements. The avionics design, which evolved from an iterative process, identified representative avionics equipments that satisfy the performance requirements. An avionics architecture layout of these equipments in the H-60 was also prepared, and the study demonstrated that all necessary equipments (including aircraft instruments) can be accommodated in the H-60. All weight, size, crew-station design, center-of-gravity, and equipment placement restrictions for accomplishing the full 250-nautical-mile mission radius were met.

The team concluded that, in order to meet the operational requirements, "the MIL-STD-1553A data bus with integrated controls and displays is the most cost-effective architecture." Two integrated CDUs, similar to a SAICS-type control head, were proposed in the study.

2.5 TECHNOLOGY PROGRAMS

2.5.1 Army Digital Avionics System (ADAS)

Late in 1978, the U.S. Army Avionics Research and Development Activity (AVRADA) initiated an exploratory development program called ADAS, with the goal of applying a new digital system architecture to an entire aircraft system. This exploratory program for digital avionics can be broken into four distinct phases. During the now-completed first phase, the ADAS was fully defined and characterized. A system architecture was developed for the AVRADA UH-60A STAR (System Testbed for Avionics Research) aircraft on the basis of the outputs of a human factors engineering study and a detailed analysis of the electronic sensors and subsystems on board the aircraft. Candidate systems for integration and multiplexing were first identified and then defined by electrical interface parameters, including signal levels, input/output impedances, and repetition rates. Multiplex data bus controller hardware was designed, fabricated, and delivered to the AVRADA digital hot bench, together with appropriate software support.

The ADAS is now undergoing hardware fabrication (Phase II). Delivery of multiplex and control/display equipment to the Army is scheduled for September 1981. At that time, hot-bench system testing (Phase III) will be initiated. During this phase ADAS will be evaluated to assure that all required functions can be easily performed. In addition, the hot-bench facility will be used for pilot familiarization. Because of the flexibility of the ADAS architecture any changes required as a result of the hot-bench phase will be incorporated by software modification. At the end of the hot-bench evaluation (approximately one year), AVRADA will begin the installation of ADAS into the UH-60A STAR.

During Phase IV, ADAS will be flight-tested in the UH-60A STAR. This vehicle will provide Army pilots an opportunity to fly an integrated digital aircraft and will provide valuable feedback as a system-integration tool for AVRADA.

The software for ADAS is being developed in the PASCAL higher-order language and the SDP-175 computer instruction-set architecture.

2.5.2 Navy Advanced Integrated Display System (AIDS)

The goal of AIDS is to develop a modular set of displays and controls, together with associated processing and data multiplexing elements that can be applied to all future Navy aircraft. Objectives are improved pilot performance, reduced weight and life-cycle cost, and improved mission reliability. The extensive utilization of multiplexing is a key factor in helping to achieve all of these objectives. Multiplexing will be applied in three distinct areas: (1) narrowband serial digital (i.e., 1553B), (2) wideband video suitable for transmitting TV raster formatted data, and (3) high-speed parallel digital suitable for transmitting data between digital modules on a common back panel.

The advance development model (ADM) of AIDS will be implemented with currently available technology. It will be used to validate system concepts and software. It will also be designed with sufficient flexibility so that advanced multiplexing technologies can be incorporated and demonstrated as they become available.

2.5.3 Avionics System Integration Demonstration (ASID)

The ASID program, managed by AFSC's Air Force Avionics Laboratory, is an outgrowth of the Laboratory's previous DAIS (Digital Avionics Information System) program, which led to MIL-STDs-1553, -1750, and -1589. ASID consists of three technology projects whose development will allow upward compatibility of new controls and displays with the evolving avionics MIL-Standards.

2.5.3.1 Integrated CNI Avionics (ICNIA), Project 2538

The ICNIA project will develop the technology necessary to contain all similar RF functions (UHF/VHF, VOR/ILS, JTIDS, and GPS) in a single integrated avionics LRU.

2.5.3.2 Advanced System Avionics (ASA), Project 2734

The ASA project has two objectives: (1) to provide for continuing avionics subsystem architectural advancement of controls, displays, and other subsystem LRUs through simulation to permit the effective exploration of evolving technologies (such as fiber optics); and (2) to maintain an in-house center of expertise for support of Air Force avionics system acquisition and standardization. ASA is to assist in the systematic infusion of advanced avionics technologies into the acquisition process.

2.5.3.3 Integrated Flight Demonstration (IFD), Project 2735

The IFD project will provide the second-level technology validation needed from the first two projects by flight-testing advanced development models.

2.6 CONCLUSIONS

A summary of the principal characteristics of the integrated control system programs reviewed in this chapter is presented in Table 2-1.

Table 2-1. SUMMARY OF AVIONICS INTEGRATED CONTROL CONCEPTS

Aircraft	Avionics Controlled	Digital Multiplexer Bus Interface	Panel (P) Console (C) CDU	Growth Capability	Number of CDUs/ Height (Inches)
F-4E	UHF, KY, ADF, TACAN, IFF	No	N/A	N/A	N/A
UH-1(IACS)	UHF, VHF/AM/FM, KY, ADF, IFF, ILS, Doppler	Yes (1553A)*	C	SCC	2/7.12
HC-130H	UHF, VHF/AM/FM, HF, TACAN, IFF, VOR	Yes (1553A)*	C/P**	SCC	3/6.75
HU-25A (MRS)	VHF, HF, TACAN, IFF, VOR, DME	Yes (1553A)†	C	SCC	3/7.12
HH-65A (SRR)	VHF, HF, TACAN, IFF, VOR, DME, HSVD, LORAN, Flight Management	Yes (1553B)*	C	SCC	2/7.12
A-10A	F^3INS and Other	Yes (1553A)††	C	CDU	1/7.87
F-15A	UHF, KY, ADF, IFF, Antenna Selection, and Other	Yes (Nonstandard)	N/A	N/A	N/A
F/A-18	17 CNI Subsystems and Other	Yes (1553A)	P	CSC	1/5.56
757/767	Flight and Performance Management	Yes (ARINC 429)	C	FMC	2/9.00
L1011	Fault Isolation	Yes (ARINC 429)	C	SCC	1/7.12
KC-135 (Initial)	VHF, KY, FSAS, INS	Yes (1553B)*	C	SCC	2/7.12
H-X	Similar to SRR	Yes (1553B)*	C	SCC	2/6.75

*Bus control (BC) function in system coupler computer.
**Two units in console, one on radio operator's panel.
†BC function in system coupler computer but dynamic bus allocation with RNAV subsystem.
††BUS control capability in CDU.

Among the significant characteristics of the systems listed in Table 2-1 are the following:

- All of these systems except the F-4E have a digital multiplexer bus interface. The later systems contain a microprocessor in their control head and, as in the case of the SRR, could relieve the principal aircraft computer of some of its bus control duties if required.
- Most are oriented toward control of CNI functions.
- Most are mounted in a console readily accessible to the pilot.
- The only units bigger than the A-10 F^3INS control head are the dual 757 and 767 units, which are fully integrated into the aircraft avionics architecture and control all phases of flight.
- In two-seat aircraft, a second control unit is always available to serve as back-up and to ease cockpit workload.

From these characteristics we can infer that the trend in integrated controls is to provide a multiplexed modular unit with a microprocessor capability for flexibility.

As a result of our investigation, we have determined that there are several characteristics that should be addressed for a SAICS (most of these are included in a draft SAICS specification currently under Air Force review):

- Consists of three LRUs: multiplexer, control/display, remote indicator
- Weighs 20 pounds, consumes 120 watts of power
- Is modularized for SRU access and replacement
- Meets MIL-STD-1553 bus requirements
- Operates as a stand-alone system or remote-terminal subsystem
- Has provisions for growth to control as many as 14 CNI subsystems
- For the cockpit control display LRU
  - Usually contains a CRT display
  - Displays 4 to 6 lines of alphanumeric information and scratchpad
  - Has a 12- to 16-button plug-in keyboard -- provisions for different types
  - Is approximately 8" × 5-3/4" × 6-1/2"
  - Has provision for growth of control capabilities through software reprogrammability and redundant units

The consensus of the technical community is that the SAICS concept should follow a growth-oriented architectural approach and thus cannot be considered as providing true fleet-interchangeable standard equipment.

Rather, it would provide for common hardware, standard interfaces, and common development of some software or firmware for functions prevalent in the Air Force. The actual implementation of SAICS in the fleet would probably require tailoring of the growth functions unique to each aircraft type.

There is sufficient consensus on the primary attributes of integrated controls among the developers and users to suggest that a MIL-PRIME specification approach may also be viable. Thus, in the tailoring of a unique control for a specific aircraft type, some attributes may be common with those of equipment used in other aircraft in the fleet. This would be beneficial from a human-factors point of view and, to the extent of hardware or software commonality, would moderate the LCC impact of totally unique systems.

CHAPTER THREE

DETERMINATION OF TRIAL AVIONICS FUNCTIONAL GROUPINGS

3.1 OVERVIEW

This chapter presents a review of the existing and planned avionics subsystems in five candidate tactical aircraft -- F-4E, F-15A, F-16A, F-111F, and A-10A. Following an analysis of the methods by which these subsystems are currently controlled in the cockpit and a review of plans for controlling new avionics, our proposed trial groupings of control functions suitable for SAICS are described.

For three of the candidate aircraft (F-4E, F-15A, and A-10A) much of the required information was gathered during our review of the integrated control systems discussed in Chapter Two. Since the emphasis in this study is on control of avionics functions, information on individual or integrated instrument and display avionics has not been included.

This chapter also presents a conceptual restructuring of the existing F-111F cockpit to provide space for the installation of one, two, or three SAICS-type units to integrate the existing and planned F-111F avionics control functions. This hypothetical restructuring, used as a baseline for our subsequent reliability and cost analyses, provides insight into the potential for space and weight savings through the use of integrated control heads.

3.2 REVIEW OF EXISTING AND PLANNED AVIONICS

For our avionics review, the primary source of information was the December 1980 issue of the U.S. Air Force Avionics Planning Baseline (APB). Another source of information on existing avionics was a study we performed in 1978* for the AFSC's JTIDS Program Office at the Electronic Systems Division.

In some cases, on the basis of other sources, it was necessary to make further refinements to the avionics listed in the APB. For example, the APB does not indicate planned GPS installations in any of the candidate

*ARINC Research Publication 1965-01-1-1823, *Commonality Potential for Integration of JTIDS in USAF Tactical Aircraft,* November 1978.

aircraft, nor does it indicate planned JTIDS installations for the F-16A. Both avionics subsystems have been included in our study. In many cases, avionics modifications are either in progress or have been planned for the candidate aircraft, but span our post-1985 estimate for initial installation of SAICS. For example, HAVE QUICK, a jam-resistant modification to the UHF ARC-164 radio, has already been started in some candidate aircraft. In the F-111F, it will be a swap-out to the older ARC-109 radio as well as an update to the ARC-164, which is already installed in some F-111Fs.

3.2.1 Existing Avionics Subsystems in Candidate Aircraft

The results of our review of the existing avionics are given in Table 3-1. The numbers in parentheses in the column headings after the aircraft designations are the planned FY 1985 aircraft quantities. For the F-16A, those quantities will be increasing since this aircraft will still be in production in FY 1985.

The four avionics subsystem categories in Table 3-1 are based on our understanding of the ease of control of the avionics functions listed, display and workload requirements, and the fact that some avionics are not easily controlled by a common CDU. For example, the second category of avionics could easily be controlled with a single CDU, but if the INS CDU requirement (12K of memory) were added, a second control head would undoubtedly be required to control and display present position as well as other flight planning and radio frequency information.

For the first two categories in the table, all avionics that are known to exist in the candidate aircraft are listed. (Radio altimeters are excluded because the controls are integrated into their display unit.) However, the last two categories do not necessarily constitute the aircraft's entire avionics suite. Our prior knowledge of some avionics (e.g., central air data computers, converters) suggested that they not be included, since by themselves they require no direct method of cockpit control, are too highly integrated architecturally, or have multiple controls, and are therefore not amenable to a common CDU control.

3.2.2 Planned Avionics Subsystems in Candidate Aircraft

Following the review of existing avionics, we reviewed the planned (post-1985) new avionics and their methods of control envisioned for the candidate aircraft. The results of this review, with schedule dates, are presented in Table 3-2. For the sake of completeness, known modifications prior to 1985 are included. The table, divided in much the same way as Table 3-1, reflects the December 1980 Avionics Planning Baseline (APB) document and other information reviewed. We consulted system and item managers and SPO personnel to ensure that we used the most current planning information and to determine whether they intended to modify existing controls or install new ones to handle the new avionics. (The persons consulted are listed in Appendix A.) In some cases, we could not establish whether the candidate aircraft would receive the planned avionics. These cases are identified by a "TBD" in Table 3-2.

Subsystem	Installed Avionics by Aircraft Type				
	F-4E (502)	F-15A (301)	F-16A (663)	F-111F (84)	A-10A (616)
Communications and Communications Crypto					
UHF	ARC-164 or HAVE QUICK	(2)ARC-164 or HAVE QUICK	ARC-164 or HAVE QUICK	ARC-164, 109, or HAVE QUICK	ARC-164 or HAVE QUICK
VHF-AM/FM or VHF-AM and VHF-FM			ARC-186		(2)ARC-186 or 807 and 622
HF				ARC-123	
U/VHF-Crypto	KY-28	KY-28 or 58	KY-58		KY-28 or 58
R-NAV and Identification					
UHF/ADF		OA-8639		ARA-50	OA-8697
TACAN	ARN-84 or 118	ARN-118	ARN-118	ARN-84	ARN-118
VOR/ILS	ARN-127	ARN-112	ARN-108	ARN-58	ARN-108 and 127
Antenna Selector	MS35058	C-9011/ARA	16E1080	C-4808	160D180340
LORAN C/D	IR-2086				
RDR Transponder	SST-181X or UPN-25				UPN-25
IFF Transponder	KY-532	APX-101	APX-101	APX-64	APX-101
Transponder Crypto	KIT-1A	KIT-1A	KIT-1A	KIT-1A	KIT-1A
IFF Interrogator	APX-80 or 81	APX-76			
Interrogator Crypto	KIR-1A	KIR-1A			
INS, EW, and CORE					
INS	ASN-63 (some aircraft)	ASN-109	SKN-2416	AJN-16	F^3INS
RHAW Receiver	APR-38				
EW Receiver	ALR-46 or 69	ALR-56	ALR-46 or 69	ALR-62 (some aircraft)	ALR-46
IR Receiver	AAQ-8	ALQ-153 or 159	AAR-XX	AAR-34	
Jamming Transmitter	ALQ-119 or 131	ALQ-119 or 131	ALQ-119 or 131	ALQ-94	ALQ-119 or 131
TEWS		ALQ-128 or 135			
Chaff Dispenser	ALE-40 (some aircraft)	ALE-45	ALE-40	ALE-28	ALE-40
Auxiliary Flight Reference System	AJB-7	ASN-108	ARU-50	A24G-26C	ASN-129
Flight Director System	CPU-82	CP-1075/AYK	CPU-XXX	CPU-76	CPU-80
Mission-Unique					
Central Computer		CP-1075/AYK		(2)AYK-6	
Navigation Computer	ASN-46			AJQ-20	
Fire Control Computer	ASQ-91	AWG-20	M-362F		
Armament Control or Stores Management	AJB-7	AWG-20	GD-8080	AWW-5	AWG-ACS
HUD	ASG-26	AVQ-20	AVQ-HUD	ASG-27	ASG-29
TF/TA Radar				APQ-128 or 146	
Attack Radar	APQ-120	APG-63	APG-66	APQ-144 or 161	
PAVE TACK	AVQ-26 (some aircraft)			AVQ-26 (some aircraft)	
Strike Camera	KA-18A/25		HUD CAM	KB-18A	KB-26A
Navigation Display Panel		C-8847		ID-1748	
CCU Panel				C-8586/AYK	
Weapon/Stores Panel				12E44201-807	ACP

Table: *Table 3-1.* EXISTING AVIONICS IN CANDIDATE AIRCRAFT

Table 3-2. PLANNED AVIONICS IN CANDIDATE AIRCRAFT

Subsystem (FY Schedule)	Planned Installations in Candidate Aircraft					Probable Cockpit Control Requirements
	F-4E	F-15A	F-16A	F-111F	A-10A	
Communications and Communications Crypto						
SEEK TALK (1984-88)	X	X	X	X	X	New control
ARC-186 (1983-90)	X	X	✓	TBD	✓	New control
SINCGARS (VHF-FM) (1988-90)			TBD		X	New control
ARC-190 (1982-84)				X		New control
Adaptive HF (1986-?)				TBD	X	New control
KY-58 (1984-?)	TBD	Some	✓	X	Some	New control
KY-75 (1984-?)				X	TBD	New control
R-NAV and Identification						
GPS (1984-?)	TBD	X	X	X	X	Modified or new control
JTIDs (1984-90)		X	X			Two new controls
MLS (1986-92)	X	X	X	X	X	New control - need both ILS and MLS during transition
MARK XII TIP (1983-?)	X	X	X	X	X	Old control
NATO IFF (1990-?)	X	X	X	X	X	New control
INS, EW, and CORE						
F^3INS (1983)				X	✓	New control
ALR-69 (1984-89)				X		Old control
ALQ-165 (1986-90)			X			Modified control
Mission-Unique						
New Computers (1983-89)		X	X	X	TBD	New control
MRR (1986-?)	TBD			TBD		New control
AMRAAM (1986-?)		X	X			Modified SMS control panel
Wasp (1988-?)			X	X	X	Modified SMS control panel
LANTIRN (1985-?)			X	TBD	X	Modified or new control
FSAS	TBD	TBD	TBD	TBD	TBD	New control
SMS (Weapons Control)	✓	✓	✓	✓	✓	Existing panel control

X - *To be installed.*
✓ - *In aircraft.*
TBD - *To be determined.*

Our review of planned avionics subsystems produced the information presented in the following subsections.

3.2.2.1 Communications and Communications Crypto

SEEK TALK is an anti-jam (AJ) system planned for installation in the candidate aircraft by 1988 as a module change to the ARC-164 radio. SEEK TALK is the more permanent solution to the ARC-164 AJ HAVE QUICK modification now in progress. Three versions of SEEK TALK have been configured, but the same control head is planned for each.

The ARC-186 is a relatively new VHF-AM/FM radio already installed in the F-16A and some A-10A aircraft. In the A-10A, it takes the place of two radios. The ARC-186 is scheduled for installation in the F-4E and F-15A.

SINCGARS (VHF-FM), an Army program, is a Single Channel Ground and Airborne Radio System that will be used primarily to communicate with ground forces. Current plans show that SINCGARS will be installed in the A-10A, and possibly the F-16A, between 1988 and 1990.

The ARC-190 will be the new Air Force standard HF radio. It is currently in preproduction and is scheduled to be installed in the F-111F aircraft before 1985 as a replacement for the aging ARC-123.

Adaptive HF, a program to develop a new digital HF radio which can automatically "adapt" to the ionospheric propagation and interference environment, apparently is planned to be installed in the A-10A.

The KY-58 and KY-75 are existing secure-voice cryptographic units for the UHF/VHF and HF radios, respectively. The KY-58 is the latest version of the KY-28 and has the same interface and controls. All of the candidate aircraft have secure voice with the exception of the F-111F, for which units have been planned.

3.2.2.2 Radio-Navigation and Identification

GPS is a new radio navigational system that uses satellites to provide worldwide, highly accurate three-dimensional positioning information. Initial installation, beginning in 1984, has been planned for the F-16A, F-15A, A-10A, F-111F, and, possibly, the F-4E. GPS control requirements, which are similar to INS control requirements, will probably be met by modification to existing panels.

The Joint Tactical Information Distribution System (JTIDS) is planned for installation in the F-16A and F-15A during the period 1984 to 1990. The most current and detailed JTIDS installation information is available for the F-15A.* Two controls -- mode control and secure data control -- must be added to the F-15A to support JTIDS. To install the mode control in the F-15A left-hand console, three existing panels (BIT, AAI, and Ground Power Panels) will have to be relocated.

The Microwave Landing System (MLS) is planned to be added to the candidate aircraft during the period 1986 to 1992. Eventually, this system will replace the existing worldwide Instrument Landing System (ILS). For aircraft with sufficient avionics bay and cockpit space, it would be desirable to install MLS and retain the ILS during the transition period.

A Mark XII Technical Improvement Program (TIP) is planned to define and evaluate improvements to the existing crypto-secure system to ensure more effective performance under combat conditions. This improved version of the existing Mark XII system is planned for installation in all of the candidate aircraft beginning in 1983. It will use the same controls as the old system.

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*ESD-TR-78-149, *Study to Define the Integration of JTIDS into Four F-15A Test Aircraft,* 6 January 1978.

NATO IFF, a cooperative NATO identification system, is projected for installation in the candidate aircraft beginning in 1990. For our study, we assumed that the NATO IFF system would replace existing transponder and interrogator systems in the candidate aircraft. We also assumed that the F-16A would be provided with an interrogation capability, which it does not currently have.

3.2.2.3 INS, EW, and CORE

For the candidate aircraft, two Group 3 modifications (F^3INS and ALR-69) are planned for accomplishment before 1985 and thus were not included in our analyses. The F^3INS control was discussed in Chapter Two; the ALR-69 uses the same control as the ALR-46. The ALQ-165 ECM set is planned for the F-16A. We assumed that installation of this avionics subsystem in the aircraft would require modification of an existing control.

3.2.2.4 Mission-Unique

From our review and knowledge of planned avionics, computer replacements and updates have been forecast for the F-111F, F-16A, and F-15A. In addition, a mission computer will probably be required for the A-10A in the future, because of that aircraft's expanding weapon system architecture. These modifications not only require new controls and panels, but will also have a considerable impact on existing avionics software. For example, a new fire control computer is planned for the F-16A during its Multinational Staged Improvement Program. This computer is to be installed, together with an additional bus, new displays, and a CNI keyboard control (on the HUD panel). The CNI keyboard control will also provide a means of inputting data and controlling the computer. The existing fire control navigation panel (FCNP) will be removed, with its control functions being distributed between the HUD CNI keyboard and the new data entry display, sensor, and avionics power panels.

Multi-Role Radar (MRR) is a new advanced-technology program established to develop a solid-state multimission (air-to-air and air-to-ground) radar for one or more aircraft. A leading contender aircraft for MRR at present is the Long Range Combat Aircraft (LRCA). Our review of existing advanced radar controls indicates that they are fully integrated with, and somewhat unique to, each aircraft's fire control and display systems. If, for example, MRR were installed in the F-111F, it would conceivably replace both the existing terrain-following/terrain-avoidance and attack radars, necessitating new displays and controls.

The Advanced Medium Range Air-to-Air Missile (AMRAAM) is an all-weather, all-aspect air-to-air missile, with improvements in aerodynamic performance, operational utility, effectiveness, and reliability. AMRAAM is planned for the F-16A and F-15A starting in 1986.

Wasp, a 100-pound mini-missile with capabilities for lock-on after launch, hit-to-kill, and independent target-acquisition and tracking, is designed to be launched from an aircraft pod some distance from enemy armor. Wasp is planned for the F-16A, A-10A, and F-111F, starting in 1988. It is planned to control both AMRAAM and Wasp by using modified stores (weapons) control panels.

LANTIRN (Low Altitude Navigation Targeting Infrared for Night) is an under-the-weather manual terrain-avoidance (TA) system established to provide the tactical air forces with an improved 24-hour capability to acquire, track, and destroy ground targets with a single-place aircraft. LANTIRN is programmed for integration into the F-16A, A-10A, and, possibly, the F-111F, starting in 1985. For the F-16A flight-test configuration, as many as four control panels are envisioned for full integration of LANTIRN. The interfaces to the three major displays (Stores Control, HUD, Radar/EO) will also be affected. For the A-10A, at least two LANTIRN control panels are envisioned, as well as an "eyebrow" panel and other modifications to the cockpit.

The Fuel Savings Advisory System (FSAS) is planned for larger aircraft such as the KC-135 and C-5. This modification program has recently gained high-level emphasis because of the dramatic increase in fuel costs. If installed in any of the candidate aircraft, it might require new controls.

All of the candidate aircraft have some form of a stores management set (SMS) for weapons control. For the F-16A the stores control panel interfaces with the stores management computer via the 1553A bus. For the F-15A, the armament control panel interfaces with the armament control computer via a nonstandard digital bus. New weapons require changes to at least the stores (or armament or weapons) control panel.

3.3 REVIEW OF AVIONICS CONTROLS

Using our Technical Order library, we thoroughly reviewed each existing avionics subsystem and its method of control in the candidate aircraft. This review revealed that in many cases standard avionics controls have been modified to meet the needs of a specific cockpit. Samples of our findings with respect to controls for avionics in each category are provided in the following subsections.

3.3.1 Communications and Communications Crypto

The ARC-164 UHF subsystem is installed in all of the candidate aircraft. In the F-111F, the ARC-164 UHF radio control is installed in the right main instrument panel; it measures 4.875" H × 5.75" W × 5.34" D, and weighs 4.32 pounds. Figure 3-1 illustrates the control panel pin connector layout and LRU interfaces. This control has eight interfaces. The KY-58 crypto subsystem is not yet installed in the F-111F, and the F-111F ARA-50 ADF is unique among the aircraft reviewed.

The method of controlling the same ARC-164 avionics subsystem varies from aircraft to aircraft. Although the ARC-164 UHF subsystem can be

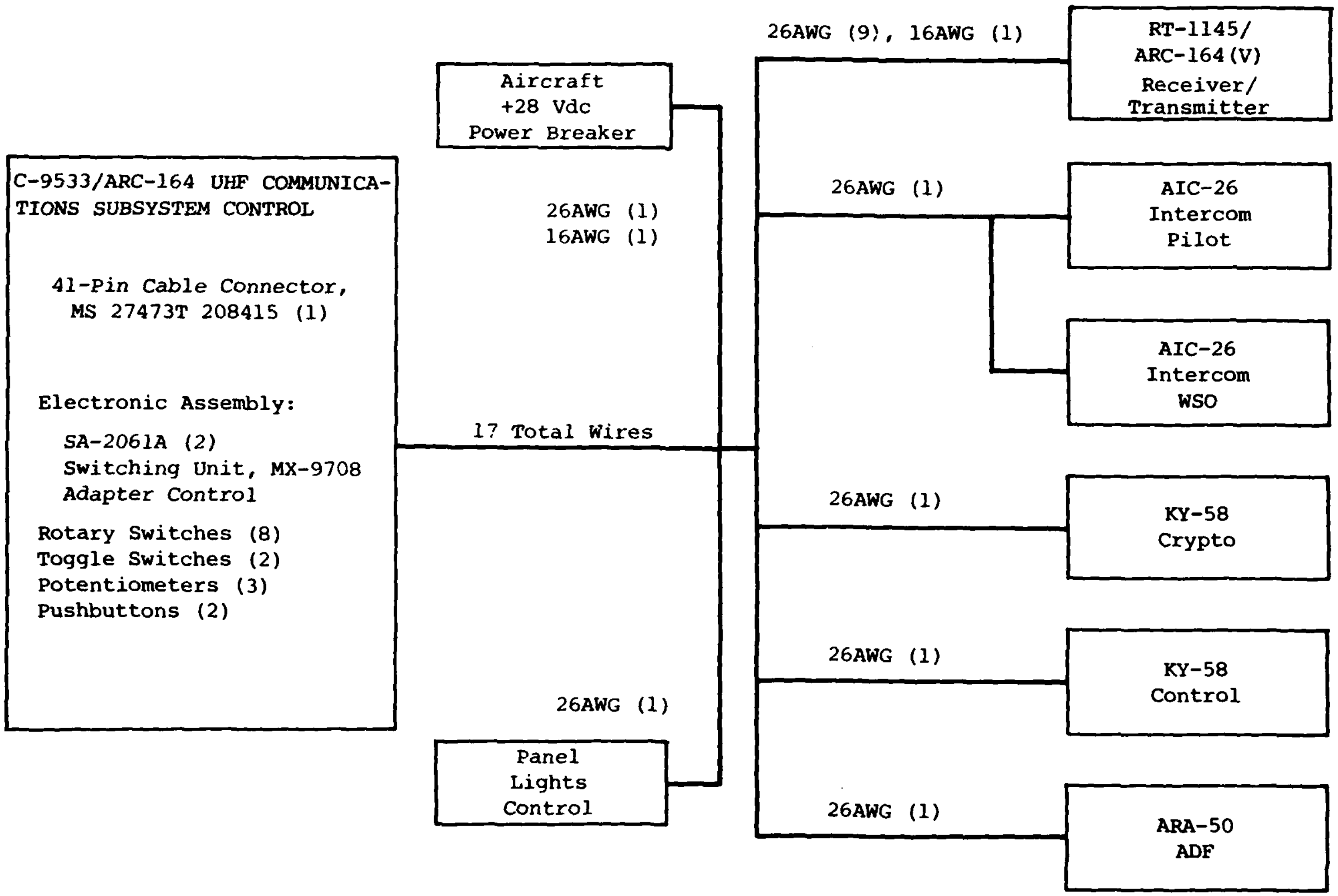


Figure 3-1. F-111F UHF COMMUNICATIONS CONTROL INTERFACE

installed remotely or as one panel-mounted unit, its control head appears the same in both cases. The F-16A and A-10A contain panel-mounted ARC-164 subsystems, while the F-111F contains the remote control. In the F-4E, the ASQ-19B electronic central control head controls the ARC-164. Two different nonstandard units control the two ARC-164s in the F-15A.

3.3.2 R-Nav and Identification

The ARN-118 TACAN Navigational Set is a typical Radio-Navigational (R-Nav) system installed on most Air Force tactical aircraft. Eight alternative control units provide for choice of panel lighting voltage (5 volts or 28 volts) and color (red or white) and panel height (3.00 inches or 2.25 inches). All units are 5.75"W x 5.43"D (including knobs and rear connector) and weigh two pounds maximum.

The APX-64 identification subsystem contains typical identification controls. (The controls for all Mark XII subsystems have been designed to a common DoD AIMS specification.) The APX-64 IFF transponder control panel is 5.25" H × 5.75" W × 3.09" D, and weighs 2.75 pounds.

During our review of IFF transponder controls, we noted that the A-10A and F-16A APX-101 control (C-6280) interface format is identical to that of the F-111F shown in Figure 3-2.

3.3.3 INS and Electronic Warefare

The A-10 F^3 INS CDU described in Chapter Two is representative of INS control requirements. Typical electronic warfare (EW) controls are listed in Table 3-3. We made the following observations:

- Some EW subsystems require two or more controls.
- Controls for different EW subsystems are interchangeable in some aircraft, but not in others.
- Controls for the same EW subsystems vary among different aircraft.

From our review we could find no technical obstacles to integrating EW subsystems controls in the same way as CNI subsystems. Core avionics, such as flight management systems, were unique to aircraft type.

3.3.4 Mission-Unique

The existing F-16A stores management set (SMS) is a good example of a state-of-the-art mission-unique function. The SMS consists of three major LRUs and is fully integrated into the aircraft digital bus architecture. The stores control panel provides an alphanumeric status display and a manual means of controlling the weapons. The central interface unit provides the MIL-STD-1553 interface to the attack radar, radar electrooptical display, HUD, and fire control computer. The remote interface unit is an armament multiplex terminal and switching center for power, release control, store status, and analog signals.

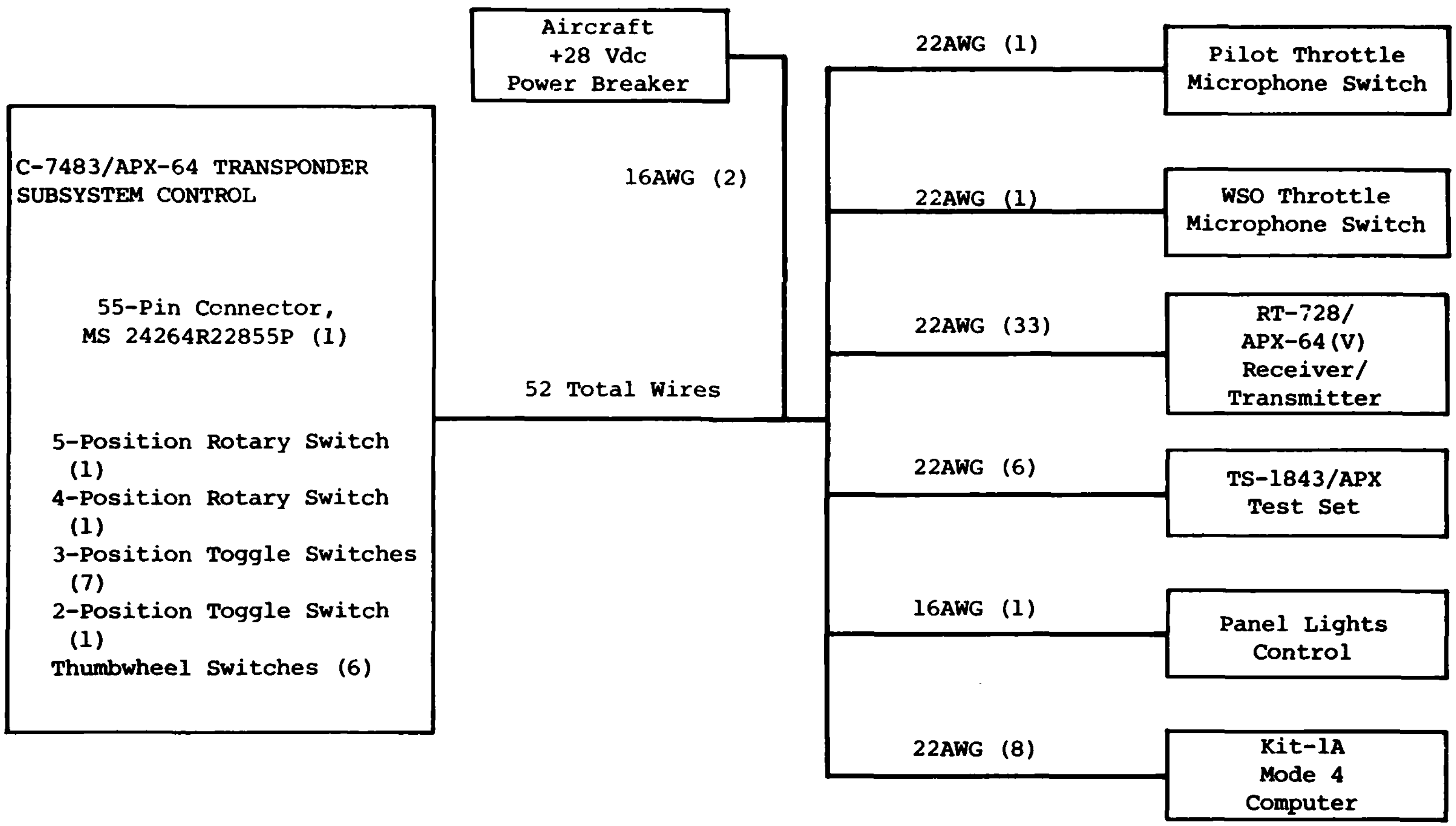


Figure 3-2. F-111F IFF TRANSPONDER CONTROL INTERFACE

Table 3-3. TYPICAL ELECTRONIC WARFARE SUBSYSTEM CONTROLS

Subsystem	Aircraft	Control	Remarks
ALR-46	F-4E, A-10A F-16A	C-10371 C-10372	Controls are same size and weight.
ALR-56	F-15A	C-9428 C-9429	Two required.
ALQ-128	F-15A	C-9428 C-9429	Same as ALR-56.
ALQ-135	F-15A	C-9428 C-9429	Same as ALR-56.
ALR-69	F-4E, A-10A F-16A	C-10371 C-10372	Same as ALR-46. Same as ALR-46.
ALQ-119	F-4E F-15A, 16A, A-10A	C-6175 C-7854 or C-9492	
	F-111F F-16A	C-9492 C-10725	Not used in F-111F.
ALQ-131	F-4E, F-15A, F-16A, F-111F, A-10A F-15A, A-10A	C-6175 or C-9492 C-7854	Not used in F-111F.

3.3.5 Direct 1553 Bus Versus Nonstandard Interfaces

For our first two groups of avionics subsystems it was evident that existing communications, radio-navigation, and identification subsystems do not interface directly with a digital bus even though three of the candidate aircraft (F-15A, F-16A, and A-10A) contain buses. Samples of these hard-wired, remotely controlled avionics have the following approximate control-wire count:

Avionics Subsystem	Number of Control Wires
UHF Radio	30
VHF/AM Radio	30
VHF/FM Radio	35
IFF Transponder	55
VOR/DME	25
ADF	25

Today's method of implementing the bus interfaces required for each avionics subsystem without a standard "interface" is to develop a separate adapter module. This can be quite costly. Estimates from the H-X study are $100,000 for development of an adapter module (which requires a microprocessor for switching and control) and approximately $4,500 in production for a remote terminal unit containing three modules. The KC-135 study estimated $400,000 (nonrecurring) for development of a VHF adapter card and $500 per card for production. A considerable variety of adapter modules was developed under the programs discussed in Chapter Two. As an example, for the H-X, 50-pin adapter modules are envisioned. On the other hand, there are -1553 interface chips that could be used to connect some CNI subsystems directly to a multiplex bus. The F/A-18 TACAN is tied directly to the bus; -1553 interfaces exist for the F^3INS, ARC-182 and ARC-186 radios, ASN-137 doppler, and ADL-82 LORAN. For the H-X program, plans are to tie most (six) of the CNI subsystems directly to a bus and the remainder through remote terminal units. Some advantages of using direct connection are ease of implementation, lower cost, and less complexity, while a disadvantage is the possibility of exhausting the 32 addresses available to a MIL-STD-1553 system for command response. After reviewing trends and the current state of the art in multiplex bus interfaces, we assumed for our analysis that all post-1985 avionics would be produced with a -1553 bus interface capability.

3.4 SAICS TRIAL AVIONICS FUNCTIONAL GROUPS

For purposes of cost and failure criticality analyses, it was necessary to select representative avionics subsystems within each of the functional groupings. This selection is a "trial" selection; later in the report, we will make recommendations as to the suitability of each subsystem for integrated controls.

Table 3-4 depicts the existing and planned avionics (by functional group) that we determined to be representative of SAICS-controlled avionics. For the first three groups, use of a SAICS would reduce the existing major "conventional" control-head count in our candidate aircraft from a range of 13 to 15 to a range of 3 to 5 (two or three SAICS and one or two manual backups). For the "generic" SAICS, we assume the use of standard avionics subsystems wherever possible.

We had insufficient failure data and integration information to assess the quantitative impact of the following advanced units: SINCGARS, LANTIRN, WASP, and AMRAAM. We eliminated the flight management types of systems because they are normally designed as a part of the aircraft architecture at inception.

Table 3-4. SAICS TRIAL AVIONICS FUNCTIONAL GROUPS

Representative Avionics Subsystems	Typical Type of Unit Controlled
Group 1: Communications and Communications Crypto	
UHF	ARC-164
VHF-AM/FM	ARC-186
HF	ARC-190
SEEK TALK	--
UHF/VHF Crypto	KY-58
HF Crypto	KY-75
Group 2: R-NAV and Identification	
UHF/ADF*	OA-8697
TACAN*	ARN-118
VOR/ILS*	ARN-127
ILS*	ARN-108
Antenna Selector	C-4808
IFF Transponder	APX-101
Transponder Crypto	KIT-1A
IFF Interrogator	APX-76
Interrogator Crypto	KIR-1A
GPS	--
MLS*	--
NATO IFF	--
Group 3: INS and EW	
INS	F^3INS
EW Receiver*	ALR-69
Jamming Transmitter*	ALQ-131
Chaff Dispenser	ALE-40
Group 4: Mission-Unique	
Mission Computer*	M-362F
Strike Camera	KB-26A
Weapons Computer*	GD-8080
MRR*	APG-63

*In addition to SAICS CDU, would require interaction with other controls or indicators/displays not listed.

3.5 F-111F COCKPIT CONCEPTUAL RESTRUCTURING

To provide a baseline for our reliability and cost analyses which follow, we "conceptualized" a restructured F-111F cockpit in which one, two, or three aircraft avionics integrated control units replace existing individual controls, assuming that a 1553B multiplexer bus is installed at the same time.

3.5.1 Existing F-111F Cockpit Layout

Figure 3-3 depicts the existing F-111F two-man cockpit. As can be seen, the cockpit is extremely cramped at the present time and little spare panel space is available for new avionics CDUs.

Discussions with General Dynamics (the aircraft manufacturer) concerning F-111F cockpit space and ejection-capsule weight suggest that the F-111F is in a continuous modification cycle to update some of the less reliable and vulnerable controls. Some of these reliability updates are considered in the analyses of Chapter Four.

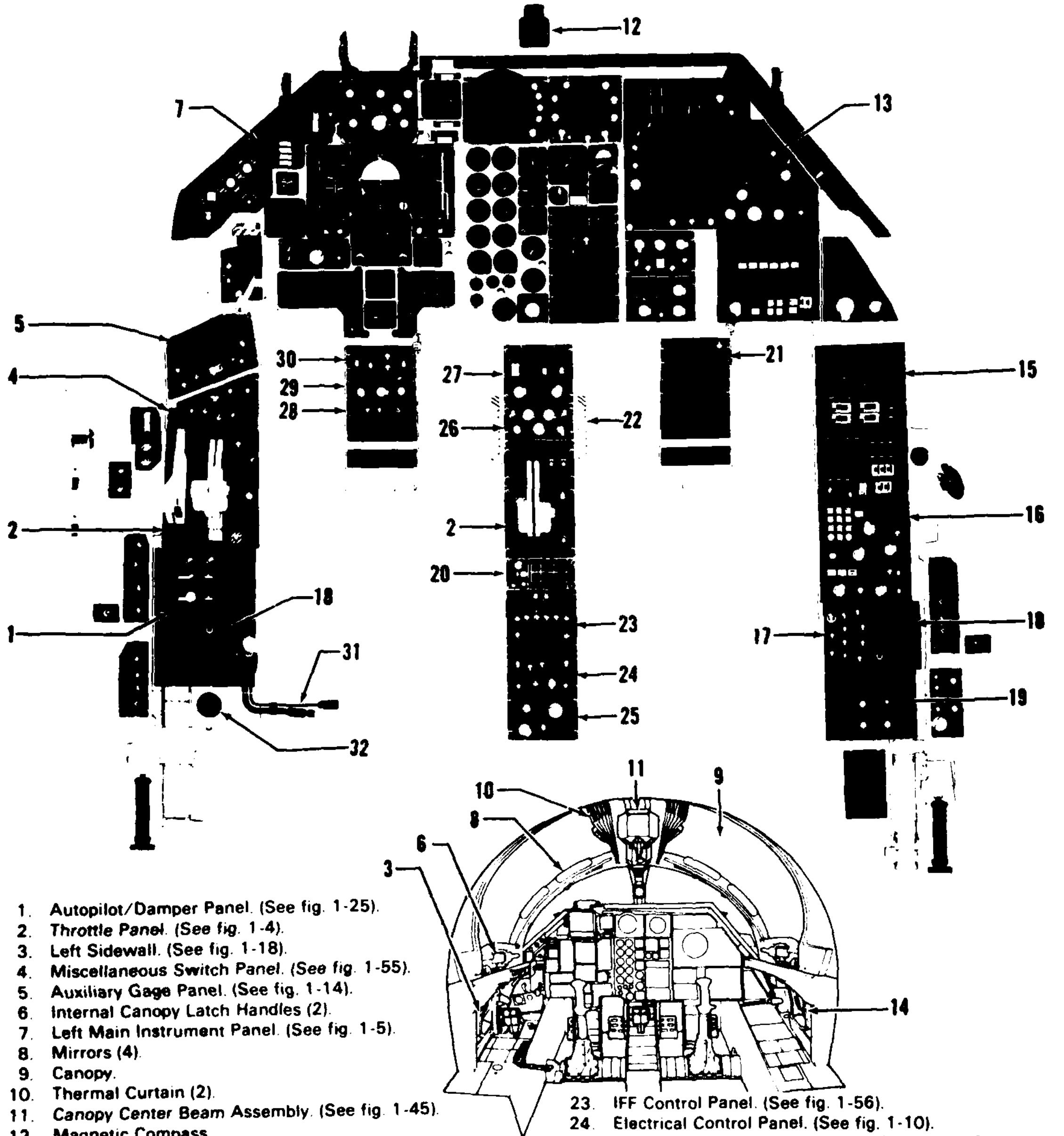
Additional discussions with aircraft and avionics manufacturers led us to the conclusion that changeover or updating of cockpit controls for the older aircraft is a problem that is normally resolved last and often by costly modification or rearrangement of existing controls. For example, the F-111F communications crypto update is about to begin, but a decision on control placement still must be made.

Also observed during this cockpit review were the scattered locations of the existing controls in our avionics functional groups. For example, five existing EW subsystem controls are in four different locations.

3.5.2 Conceptualized F-111F Cockpit Layout

Table 3-5 shows the space and weight savings achieved by replacing the existing individual controls with one, two, or three integrated control system (ICS) CDUs. Because of space limitations and the limited number of F-111F CNI controls, we determined that we could install only one SAICS to control existing Group 1 and Group 2 functions. As we proceeded to include Group 3 and 4 control functions, it was possible to find room for as many as three integrated control units. This review also highlighted the scattered locations of the five existing EW system Group 3 controls.

A review of Table 3-5 indicates that it is possible, for example, to remove the individual F-111F-unique Group 1, 2, 3, and 4 controls and save more than 315 square inches (55.2×5.75) of cockpit space and more than 57 pounds of weight. The space saving does not include the amount of additional width available from removal of the navigation display, computer control, and weapons control panels. The weight saving does not include the weight of cables and connectors that also become candidates for removal.



1. Autopilot/Damper Panel. (See fig. 1-25).
2. Throttle Panel. (See fig. 1-4).
3. Left Sidewall. (See fig. 1-18).
4. Miscellaneous Switch Panel. (See fig. 1-55).
5. Auxiliary Gage Panel. (See fig. 1-14).
6. Internal Canopy Latch Handles (2).
7. Left Main Instrument Panel. (See fig. 1-5).
8. Mirrors (4).
9. Canopy.
10. Thermal Curtain (2).
11. Canopy Center Beam Assembly. (See fig. 1-45).
12. Magnetic Compass.
13. Right Main Instrument Panel. (See fig. 1-29).
14. Right Sidewall. (See fig. 1-40).
15. Weapons Control Panel. (See fig. 1-61).
16. Computer Control Panel. (See fig. 1-60).
17. HF Radio Control Panel. (See fig. 1-50).
18. Interphone Control Panel (2). (See fig. 1-52).
*19. CMDS Control Panel. (See fig. 1-78).
*20. ECM Pod Control Panel.
21. ILS Control Panel. (See fig. 1-54).
22. Ejection Handles (2).
23. IFF Control Panel. (See fig. 1-56).
24. Electrical Control Panel. (See fig. 1-10).
25. Air Conditioning Control Panel. (See fig. 1-38).
26. TFR Control Panel. (See fig. 1-73).
27. Fuel Control Panel. (See fig. 1-8).
28. Antenna Select Panel. (See fig. 1-57).
29. Compass Control Panel. (See fig. 1-28).
30. Windshield/Anti-Icing Control Panel. (See fig. 1-41).
31. Left Station Oxygen-Suit Control Panel. (See fig. 1-44).
32. Oxygen Gage. (See fig. 1-44).

*See T.O. 1F-111F-1-3

H0000A00-005C

Figure 3-3. CREW STATION GENERAL ARRANGEMENT (TYPICAL)

Table 3-5. F-111F AVIONICS CONTROL REMOVAL, REARRANGEMENT, AND ADDITION					
Change	Control	Subsystem	Location (Reference 1F-111F-1 T.O.)	Height* (Inches)	Weight** (Pounds)
Group 1					
Remove	UHF Communications Control	ARC-164	Right Instrument Panel 13	-4.875	-4.3
Remove	HF Communications Control	ARC-123	Right Console 17	-3.750	-4.2
Move	TACAN Control	ARN-84	From Right Instrument Panel 13 to Right Console 17	-3.000 +3.000	
Add	New Control/Display Unit	Unique ICS	To Right Instrument Panel 13	+7.875	+10.0
Add	New Reversionary Communications Unit Group	Unique ICS	To Right Instrument Panel 13	+0.750	+1.0
			Group 1 Cumulative Increase	—	+2.5
Group 2					
Remove	TACAN Control	ARN-84	Right Instrument Panel 13	-3.000	-1.8
Remove	ILS Control	ARN-58	IWSO Pedestal 21	-2.250	-1.1
Remove	IFF Transponder Control	APX-64	Center Console 23	-5.250	-2.5
Remove	Antenna Select Control	UHF/IFF/TACAN	Pilot Pedestal 28	-1.125	-1.0
Add	New Control/Display Unit	Unique ICS	Same as Group 1		+1.0†
Add	New Reversionary Control Unit	Unique ICS	Same as Group 1		+0.5†
			Groups 1 and 2 Cumulative Decrease	-11.625	-2.4
Group 3					
Remove	Navigation Display Panel	ID-1748/AYK	Right Instrument Panel 13 (8.8" W)	-7.875	-26.81
Remove	Computer Control Panel	C-8586	Right Console Panel 16 (7.2" W)	-7.875	-11.01
Add	Additional Control/Display Unit	Unique ICS	Right Instrument Panel 13	+7.875	+11.0
Add	Additional Control/Display Unit	EW-Unique	Center Control Panel 20 and 23	+7.875	+11.0
Remove	Compass Control	A-246-26A	Pilot Pedestal Panel 29	-2.250	-1.0
Remove	ECM POD Control	ALQ-119/131	Center Console Panel 20	-3.000	-1.6
Remove	CMDS Control	ALE-28	Right Console Panel 19	-4.125	-2.00
Remove	ECM Threat Control/Display	ALQ-94	Right Instrument Panel 13	-1.875	-2.00
Remove	ECM RWR Control/Display	ALR-62	Right Instrument Panel 13	-3.750	-2.0
Remove	CMRS Control	AAR-34	Right Sidewall Panel	-2.625	-2.0
			Groups 1, 2, and 3 Cumulative Decrease	-29.250	-28.82
Group 4					
Remove	Attack Radar Control	APQ-144/161	Right Instrument Panel 13	-3.750	-3.0
Remove	Weapons Control Panel	12E44201-807	Right Console 15 (7.2" W)	-11.700	-18.02
Remove	TF Radar Control	APQ-128/146	Center Console 26	-3.000	-2.0
Remove	Fuel Control	12E207-855	Center Console 27	-4.875	-4.0
Remove	Strike Camera Control	KB-18A	Sidewall	-2.625	-2.0
			Groups 1, 2, 3, and 4 Cumulative Decrease	-55.20	-57.84

*Control panels are standard 5.75 in width except where indicated.
**Does not include any wiring or connector weight.
†Added functions for control units increase weight.

Figures 3-4 through 3-7 show the possible rearrangement of the F-111F cockpit with SAICS CDUs added. The approximate total weight and space savings are summarized in Table 3-6.

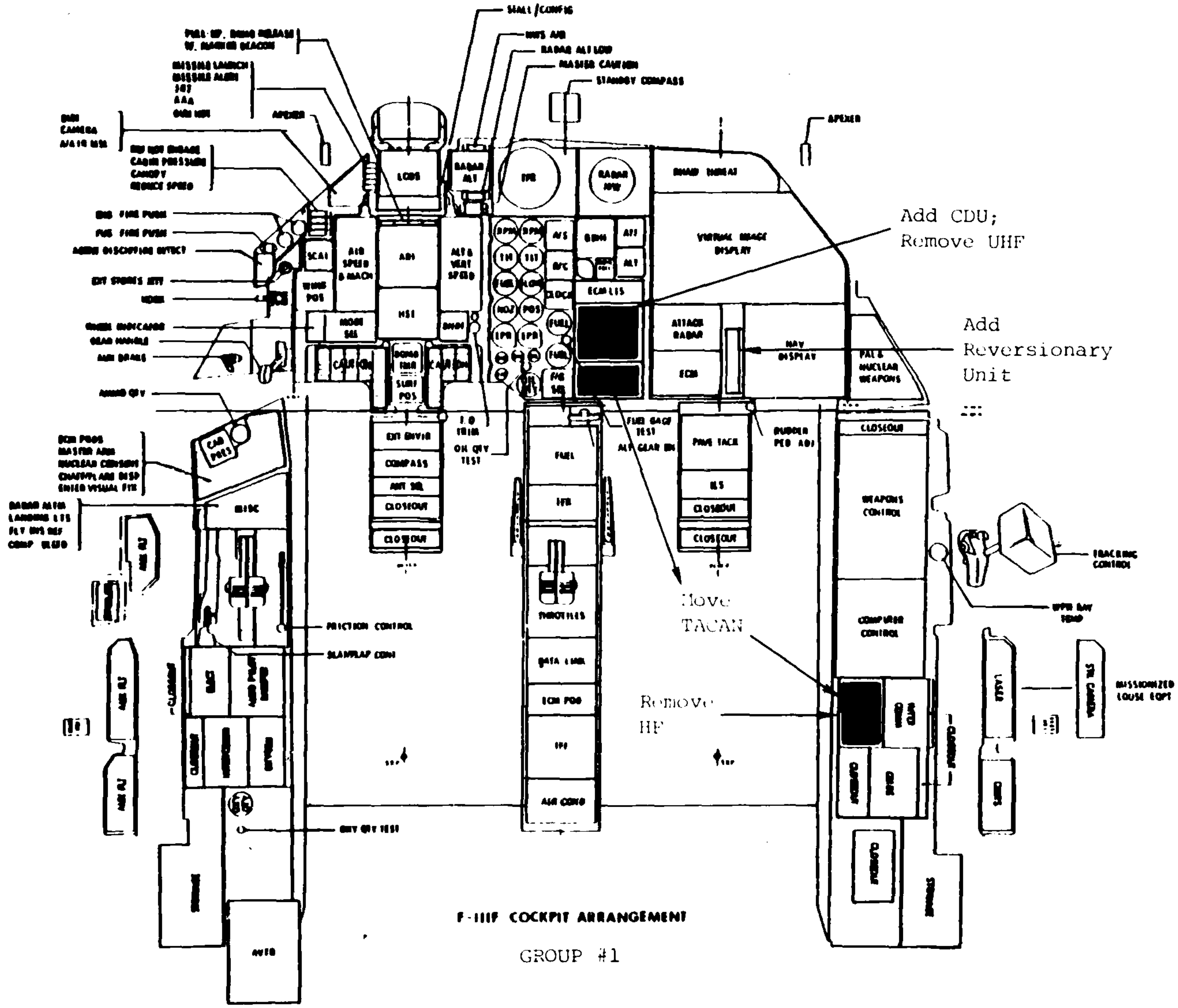


Figure 3-4. CONTROL HEAD CHANGES FOR GROUP 1 SAICS, F-111F

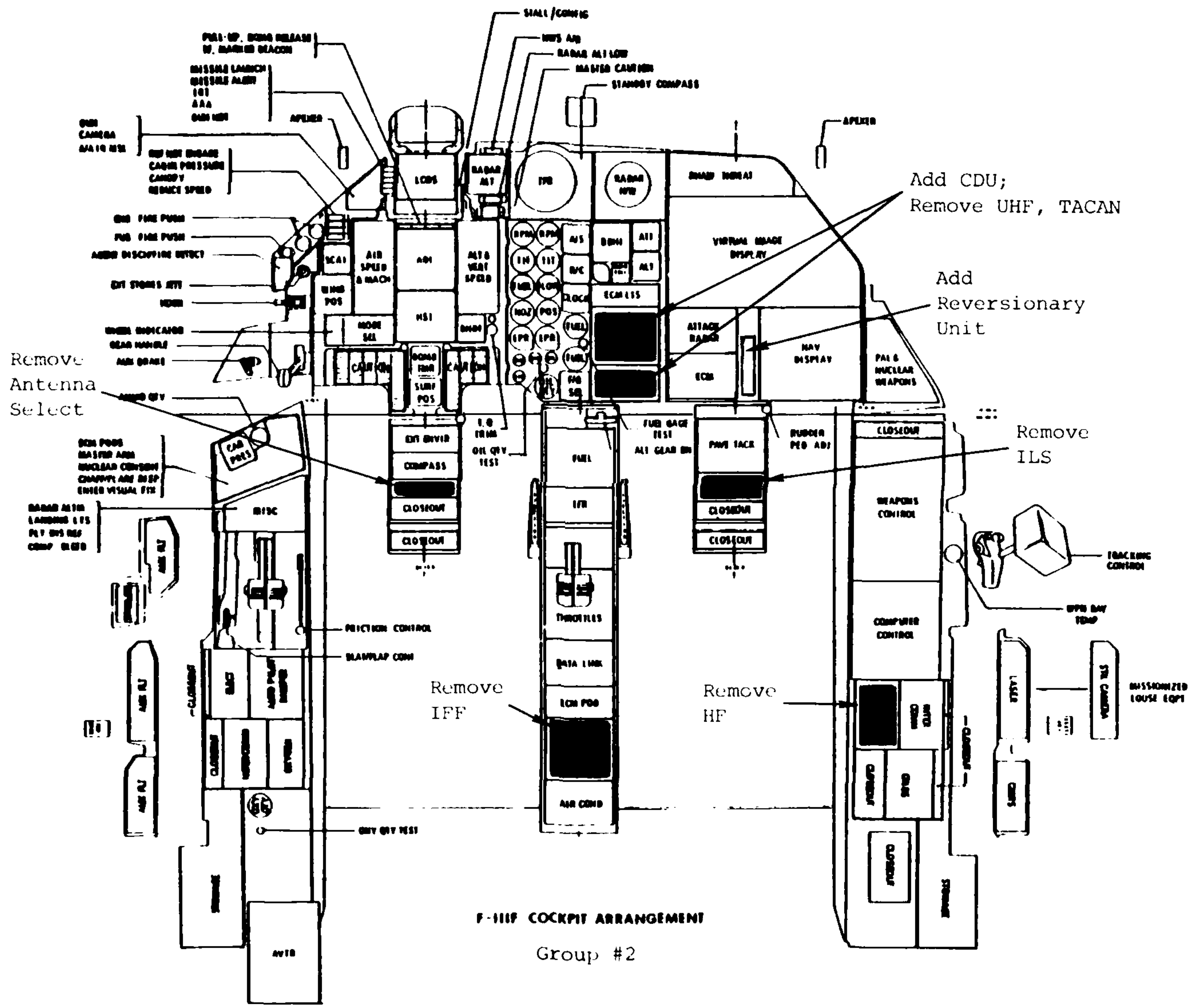


Figure 3-5. CONTROL HEAD CHANGES FOR GROUPS 1 & 2 SAICS, F-111F

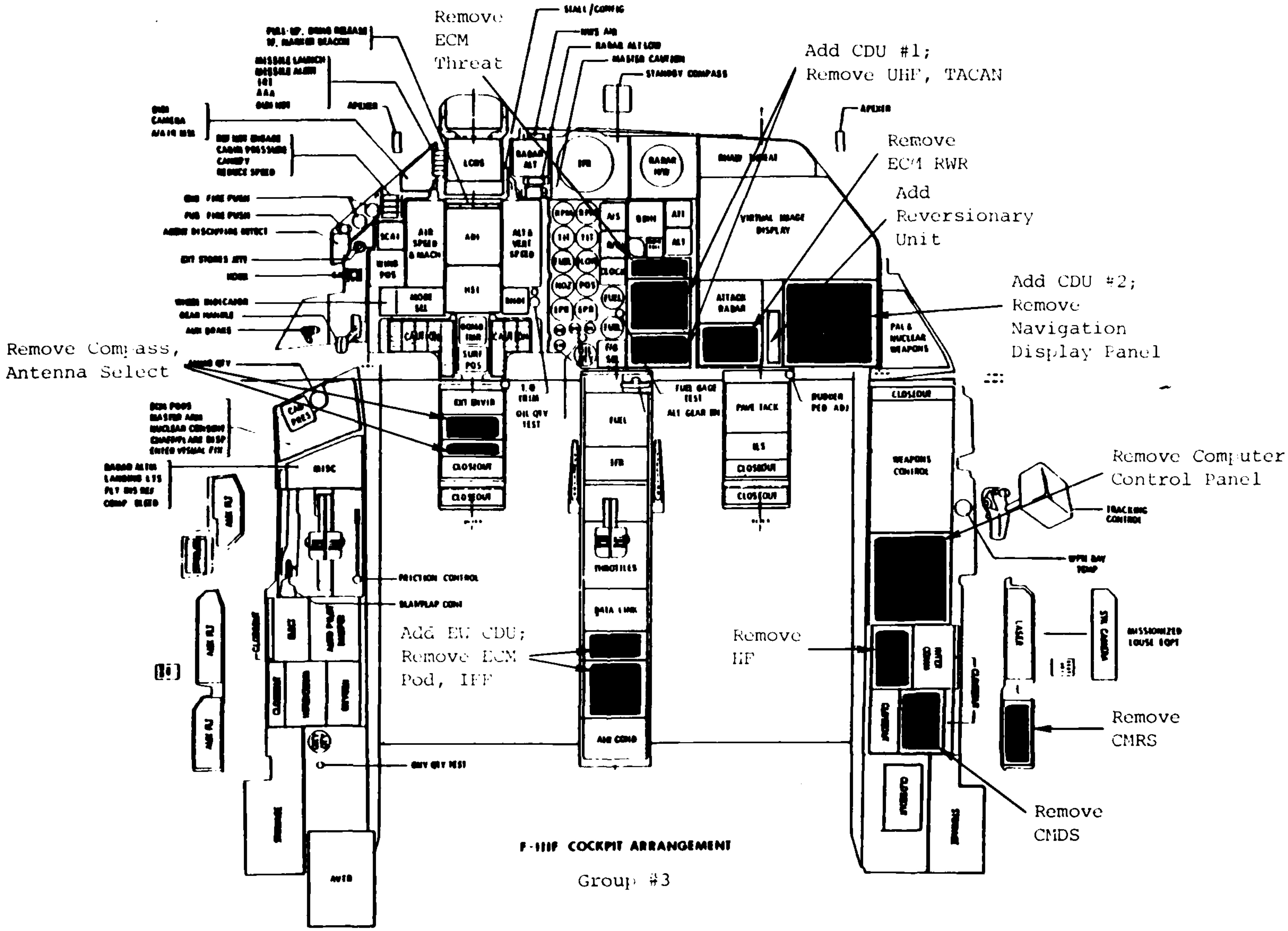


Figure 3-6. CONTROL HEAD CHANGES FOR GROUPS 1, 2, & 3 SAICS, F-111F

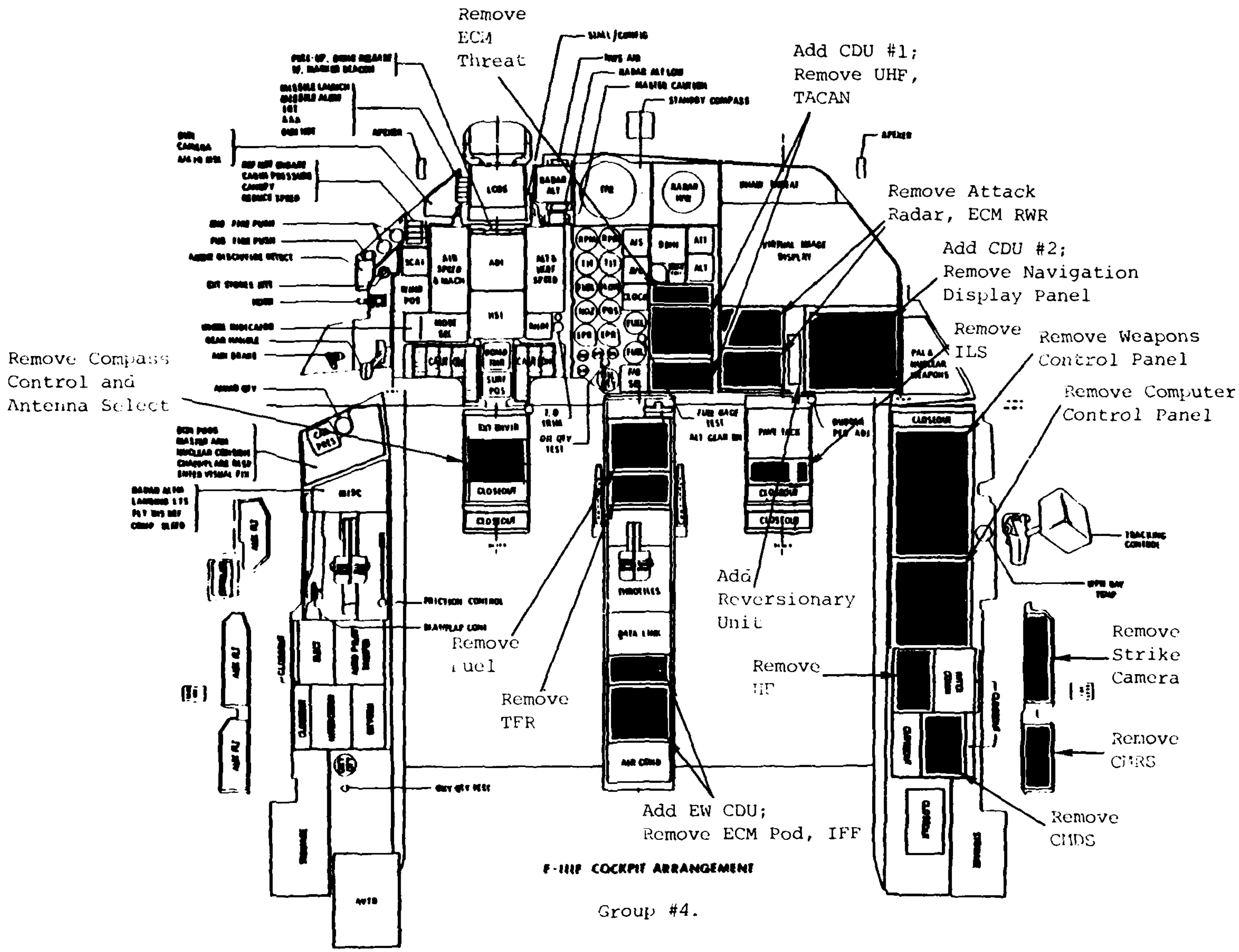


Figure 3-7. CONTROL HEAD CHANGES FOR GROUPS 1, 2, 3, & 4 SAICS, F-111F

Table 3-6. REPRESENTATIVE SAVINGS IN SPACE AND WEIGHT: F-111F INTEGRATED AVIONICS CONTROL

Control Group	Number of SAICS Units Assumed	Savings	
		Space	Weight*
1	1	None	None (Slight Penalty)
1, 2	1	$\sim$66 in.^{2}	2.4 pounds
1, 2, 3,	3	$\sim$168 in.^{2}	28.8 pounds
1, 2, 3, 4	3	$\sim$317 in.^{2}	57.8 pounds

* Savings do not include wiring or connector weights.

3.6 CONCLUSIONS

The work reported in this chapter forms the basis for our reliability and cost analyses presented in Chapters Four and Five. We developed a "generic" set of avionics functions that a SAICS CDU could control, and we grouped them into four separate categories from our review of the individual avionics interfaces. The following conclusions were reached:

- Most of the existing manual individual cockpit avionics controls in our candidate aircraft could be replaced by using SAICS CDUs under microprocessor control. Moreover, for the control of most avionics functions that require multiple individual controls today, at least some (if not all) of these functions would be suitable for a SAICS. We did observe that the difficulty in controlling specific avionics subsystems varies depending on the function (for example, radios are relatively simple to control, while armament and INS subsystem control is more complicated).
- Although we reviewed only existing and planned tactical aircraft avionics controls, other new systems such as fuel savings advisory, engine monitoring and performance, and automatic flight control are being integrated into most modern aircraft architectures, saving space and weight and easing pilot workload.
- Our conceptualized cockpit layout for the older, less architecturally integrated F-111F indicates that it is possible to provide as many as three of these control heads within the existing capsule. To save considerable space and weight, however, Group 3 functions must be added. Similar results might be expected in the F-4E and A-10A. For a single-seat A-10A tactical aircraft, for example, three different control heads (two in addition to the existing F^3INS CDU) might be envisioned to control the CNI, EW, and flight management avionics functions.

CHAPTER FOUR

FAILURE CRITICALITY ANALYSES

This chapter analyzes control-head failures that might occur during flight, describes methods for backing up individual and integrated avionics controls, and compares the failure impact of using existing individual avionics control heads rather than SAICS-type units. The F-111F aircraft is used in the analyses to illustrate pertinent factors and results. Appendix B provides typical mission profiles and flight times of the five candidate tactical aircraft, together with a synopsis of their avionics use projected for each mission phase, to support our approach and our calculation methodology.

4.1 APPROACH

We defined failure criticality as the "relative impact of losing complete control of the functions of selected avionics groupings during the mission." We used an approach similar to that for our safety criticality work performed for the Air Force Logistics Command in the mid-1970s.* We did not use the overall model developed for that effort because it took a very restrictive approach to failure criticality, emphasizing safety-of-flight items. For example, communications and identification systems are not considered safety-critical.

Our modified approach is shown in Figure 4-1.

It is difficult to generalize on the impact of avionics control-head failures across all candidate aircraft. We found that there is a wide variance in the avionics architectures of the candidate aircraft, which can affect the control-head MTBFs. In the existing F-4E and F-111F, for example, there is no avionics multiplex bus. The F-4E has the integrated CNI control set that was discussed in Chapter Two, while the F-111F has none. The F-15A has a nonstandard digital bus with a central computer for overall bus control and an integrated digital communications control. The A-10A has a 1553 bus with relatively simple controls. The F-16 has a highly integrated control architecture with multiple buses.

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*ARINC Research Publication C54-01-1-1406, *Development of Air Force Flight Safety Models*, Vol. 3, F-111A, FB-111A, September 1975.

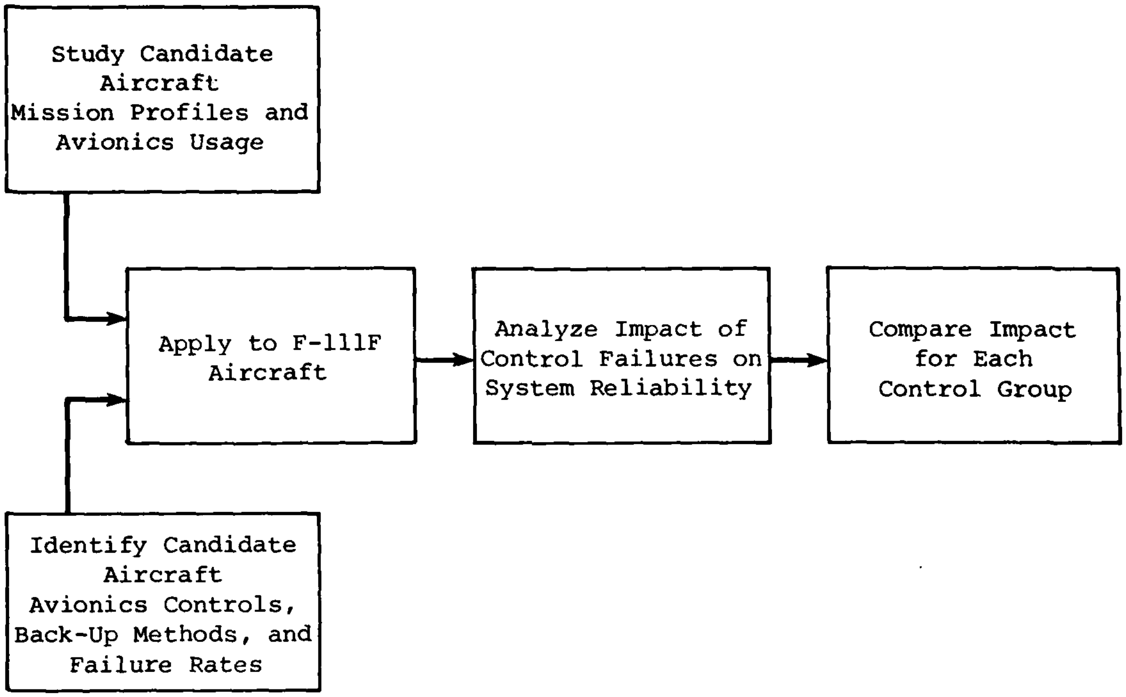

Figure 4-1. ANALYSIS APPROACH

In our review of reliability data, we noted that available control-head failure data were inconsistent. In some cases the control-head MTBF data were not separated from data on the controlled LRU. The failure data on control annunciators (e.g., alarms, lights) were incomplete and therefore could not be used for our analyses. In addition, the effect of these unique aircraft controls on MTBF is normally not consolidated and compared.

There are few reliability projections and modification engineering data concerning individual controls in future integrated avionics suites. In every case, the projections for new aircraft architectures for 1985 and beyond contain a 1553 bus. Avionics subsystem-to-bus I/O devices are expected to be built in or provided as a separate unit. New individual controls would not necessarily be hardwired to the remaining avionics as at present. Very few models and actual data are available for use in projecting the impact that these new interfaces will have on the control and overall subsystem MTBFs. We therefore decided to employ data collected from a single weapon system, the F-111F, to portray results typical of the analyses conducted. The F-111F has the longest air-to-ground (A/G) mission; further, there are several major modifications planned for it between now and 1985 that are of interest to Air Force modification planners. We consider our results typical for the other candidate aircraft since there are similarities in their avionics subsystems, particularly for the trial functions in Groups 1 through 3 as defined in Chapter Three.

4.1.1 Methodology

In reliability modeling, system reliability is defined as "the probability of performing a specified function or mission under specified conditions for a specified time."* For our analyses, an avionics control concept is defined for a designated trial group. At the start of our analyses, the individual and integrated control heads were divided into the four trial functional groups discussed previously. For each functional group, we calculated the system MTBF, system reliability, and probability of mission failure in accordance with the guidelines set forth in MIL-HDBK-217C, Appendix A.

4.1.2 Serial and Serial/Parallel Analysis

4.1.2.1 Individual Controls

To gain insight into the impact that individual control-head failures had on a mission, and to bound our results, we approached the problem in two ways. First, we calculated the reliability for the four groups serially; that is, we assumed that the controls in each group and among groups were as important to the mission as the next. Next, we determined where certain avionics subsystems in an aircraft can provide an alternate mode of operation for each other (e.g., communicating by either HF or UHF in Group 1, navigating by TACAN or ADF in Group 2). Although these types of "back-ups" generally cannot be complete back-ups in the truest sense, they were identified during our interviews with Air Force pilots as useful complements in case of an emergency and are shown as such in our mission profile tables discussed in the next section. With these types of alternate modes of operation, we calculated system reliability by using a serial method where necessary, and a parallel method where back-ups were available. After determining serial and serial/parallel reliability, we translated those results into probabilities of mission failure for each case.

Analyzing the alternate modes of operation for the F-111F INS control for Group 3 functions required subjective judgment. From our mission profile reviews, we concluded that the INS is needed during weapon delivery and has no alternate during that phase. However, the TACAN, ADF, or INS might be considered as alternate means of navigation before penetration and after egress. We considered all three as alternate modes of navigation during both the mission in-bound phase and the recovery phase. For the remainder of Group 3 functions, we chose not to assume any EW or flight director alternate modes of operation, because of the uniqueness of the equipments, although for the flight director there is an auxiliary reference system. For the additional unique mission avionics under investigation in Group 4, there were no alternate modes of operation, although loss of control of some subsystems (with degraded aircraft weapons system performance) might be acceptable for some missions -- as in the case of the F-111F dual general purpose computer.

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*MIL-HDBK-217C, 9 April 1979, Appendix A.

As a result of these factors, we developed the individual control-head reliability diagrams shown in Figure 4-2. The horizontal boxes at the top indicate the serial reliability analysis methodology discussed above, wherein each control head was considered necessary for mission success.

The boxes at the bottom of Figure 4-2 indicate a mix of avionics, which permit alternate modes of operation to "parallel" certain avionics functions, as discussed above, depending on the group combinations under analysis.

4.1.2.2 Integrated Controls

For the analysis of integrated control heads, a similar serial and serial/parallel approach was taken. We analyzed the problem using one SAICS unit for Group 1 and Groups 1 and 2. Two SAICS units plus a separate EW control head were used for Groups 1, 2, and 3 and Groups 1, 2, 3, and 4. For the F-111F, it was assumed that only one SAICS unit was on board to control those avionics functions in the first two groups because of space limitations, although a second head would undoubtedly be desired.

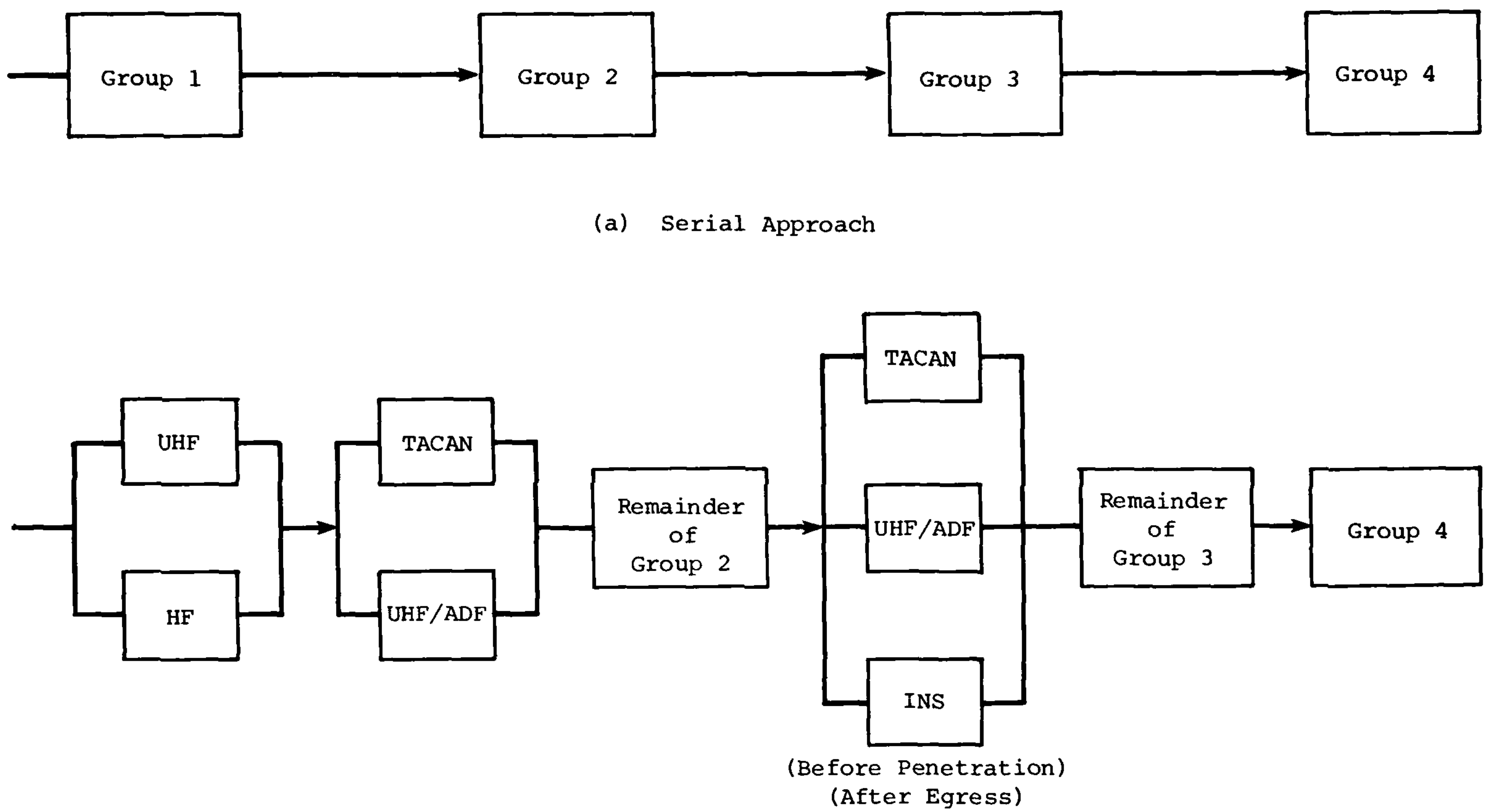
We determined that a second SAICS head would be necessary for functional control of Groups 1, 2, and 3 and Groups 1, 2, 3, and 4 because of workload and display considerations. This second identical unit is assumed to back up the first. The two units could be designated differently to meet specific mission requirements (e.g., Unit 1 for CNI control and Unit 2 for weapon delivery) but would provide complete redundancy through microprocessor control if needed. A separate integrated electronic warfare control head (Unit 3) was added to control the EW-unique functions in Group 3 so that the impact of its failure on a mission could be investigated. Our integrated-control-head reliability model diagrams are shown in Figure 4-3. The number/letter designations indicate differences in the units as more functions are controlled.

4.2 CANDIDATE AIRCRAFT MISSION PHASES AND AVIONICS USAGE

We developed representative mission profiles for each of the five candidate aircraft. We also established avionics usage factors for the equipment identified. Our data sources were ASD/XRH for the computerized mission profiles and the ASD TAC Liaison Office for the avionics usage factors and assumptions.

4.2.1 Mission Phases

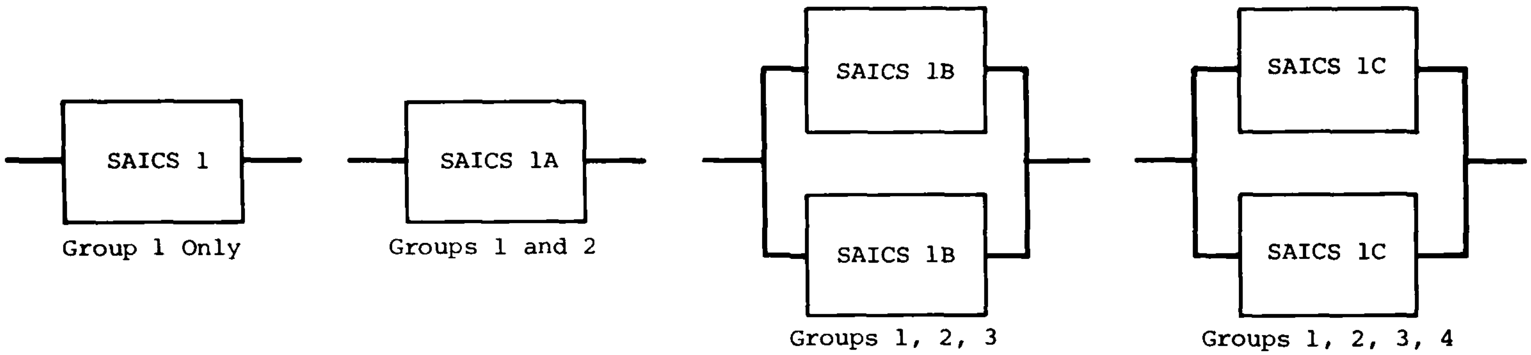
We developed typical mission profiles for the candidate aircraft using outbound, combat, and recovery phases, with further subdivisions as defined below. They are provided in detail in Appendix B. One of the candidate aircraft (the F-15A) is now used solely for air superiority, while another



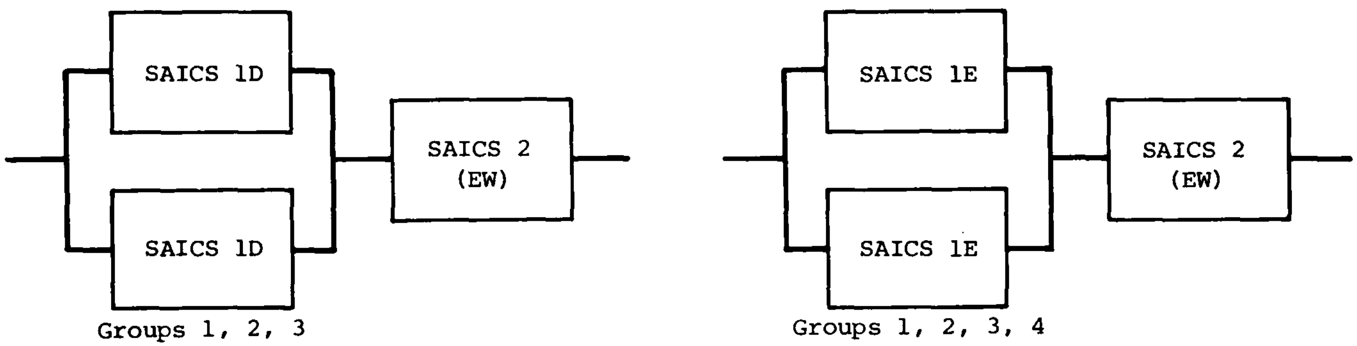
(a) Serial Approach

(b) Serial/Parallel Approach

Figure 4-2. F-111F RELIABILITY DIAGRAMS FOR INDIVIDUAL CONTROLS



(a) Serial or Parallel Approach



(b) Serial/Parallel Approach
(With third SAICS control head for EW)

Figure 4-3. RELIABILITY DIAGRAMS FOR SAICS (the A-10A) is used solely in an air-to-ground (A/G) role. The remaining three aircraft can be used for both roles. We developed both an A/G and air-to-air (A/A) scenario to cover all of the candidate aircraft, but only used the F-111F A/G mission for our reliability analyses.

4.2.1.1 Phase I: Outbound

Phase 1 consists of the following segments:

- Climb. Activities are those necessary to obtain optimum cruise configuration. The after-takeoff checklist is completed to "clean up" the aircraft configuration, contact with the controlling agency is initiated, and an accurate baseline fix is determined. (For an A/A mission, the pilot will have greater involvement with the controlling agency.)
- Cruise. Activities are those necessary to determine operational capability and to verify mission information. Systems and weapons checklists are completed, and contact with the controlling agency is maintained. Optimum altitude and cruise speed are also maintained. (For an A/A mission, timing to the combat patrol area is important. For an A/G mission, time of arrival over target and the navigation portion of the cruise profile are critical.)
- Descent (A/G Mission). Activities are those necessary to avoid detection by hostile forces while descending to penetration altitude. Coordination with the controlling agency is continued as navigation is performed under positive control.
- Descent (A/A Mission). Activities are those primarily concerned with detecting and engaging hostile aircraft (in beyond-visual-range [BVR] mode). Close coordination with the controlling agency and other flight crews is mandatory.

4.2.1.2 Phase II: Combat

Phase II consists of the following segments:

- Penetration/Weapon Release (A/G Mission). Activities are those necessary to avoid the enemy threat by evasive action as required. Final preparations for weapon release are made. Target/offset acquisition is accomplished and weapons are released. EW systems are used during all of Phase II.
- Egress (A/G Mission). Activities consist of escape maneuvers to avoid target defenses following weapon release. Threat avoidance and evasive actions are continued throughout the entire egress phase. The post-release checklist is completed.
- Combat Engagement Area (A/A Mission). Activities consist of using short- and medium-range missiles and guns for radar and visual attacks on hostile aircraft. Close coordination with other flight crews is mandatory. Coordination with the controlling agency is maintained.

4.2.1.3 Phase III: Recovery

Phase III consists of the following segments:

- Climb (A/G Mission). Activities involve those actions necessary to establish an optimum flight profile during climb. Coordination with the controlling agency is maintained because navigation is performed under positive control. Battle-damage-assessment (BDA) reporting is accomplished.
- Climb (A/A Mission). Activities consist of disengagement from the enemy, flight report, and climb. An optimum performance profile and a defensive posture against hostile aircraft and other weapons are established. Close coordination with other flight crews and the controlling agency is also maintained. An optimum performance profile (after the enemy A/A threat is no longer a factor) is established.
- Cruise. Activities are those necessary to maintain an optimum performance profile to home base. Coordination with the controlling agency is continued, because navigation is performed under positive control.
- Descent. Activities involve completing the pre-landing checklist and configuring the aircraft for landing. Contact with the home base is made, and approach to the airfield is accomplished.
- After Landing (A/A Mission). Capability for immediate combat turnaround is maintained.

4.2.2 Avionics Usage Factors

After developing mission profiles, we developed avionics "usage factors" ranging from 0 to 1 in decimal increments. These are presented in the Appendix B mission profile summaries. The usage factor was defined as that portion of time during a given mission phase in which a particular avionics subsystem required interface with the air crew. This interface, which may be interaction with a control head, display, or audio/voice, must be maintained for immediate use by the air crew. Usage factors were developed under the following assumptions:

- All avionics subsystems that include controls are operational at takeoff and when required during the mission (assumption needed to determine usage factors).
- Missions are flown in the European theater (NATO environment).
- All missions are under AWACS positive control.
- For A/G sorties, the aircraft is vulnerable to air-to-air attack as well as ground-to-air attack from start of descent before penetration to level-off at cruise altitude following target area egress.

- A/G sorties are engaged in interdiction missions in enemy territory beyond the forward edge of the battle area (FEBA), using unguided bombs or Maverick.

4.3 AVIONICS CONTROL FAILURES AND BACK-UP METHODS

After developing the mission profiles and usage factors, we conducted a more thorough review of the methods of controlling the avionics identified and grouped in Chapter Three and identified the control-head MTBFs for the F-111F aircraft. Our review included not only control of the existing avionics in the candidate aircraft, but also available back-up methods and devices that might increase the overall system reliability.

Our F-111F failure data are displayed in Table 4-1. These data, obtained from the Sacramento ALC F-111F D056 Report, include the control-head MTBFs for the F-111F avionics identified earlier in our four trial functional groups for the six-month period May to October 1980. The MTBFs are uniformly high when compared with those of the avionics subsystems they control.

Actual MTBFs were available for most of the F-111F existing individual control heads, and these were used whenever available. Those critical to our analysis, but not available (i.e., UHF, ILS, EW Receiver) were estimated by using a relationship between control-head MTBFs and occurrences of failures obtained from the Sacramento ALC. These estimated MTBF values are shown in Table 4-1 in parentheses. The unavailable PAVE TACK digital-control MTBF is assumed to be extremely high relative to the others used and thus would have little impact on our results. Since the UHF and UHF/ADF controls are in the same head, we used the same MTBF for both.

We consider these MTBFs representative of values expected in a mature weapon system. We also expect, however, that there may be a wide system-MTBF variance between aircraft with similar special control heads such as the CCU. Accordingly, we also examined the effect of increased MTBF to be obtained by an update in the very-low-MTBF F-111F HF control, navigation display panel, and CCU. All three of these units are scheduled for replacement. The projected MTBF values are estimated to be 10,700 hours for the HF, 2,500 hours for the navigation display panel, and 2,500 hours for the CCU. The HF value is a WRALC projection for the ARC-190 HF radio control; the other two are Sacramento ALC estimates.

4.3.1 Individual Control Back-Up Methods

The known control and display back-ups available for the avionics in the candidate aircraft are identified as follows:

- F-4E -- Two UHF controls, two TACAN controls, two remote UHF channel frequency indicators
- F-15A -- Two UHF controls (these include antenna selector switch for the UHF and IFF antennas)

Table 4-1. F-111F CONTROL-HEAD MTBFs, MAY THROUGH OCTOBER 1980
(94 AIRCRAFT; 8,458 OPERATING HOURS)

Group	Avionics	Nomenclature	Number of Aborts	MTBF
1	UHF	ARC-164	0	(1,700)*
	HF	ARC-123	0	211
2	UHF/ADF	ARA-50	(Uses ARC-164 Control)	
	TACAN	ARN-84	0	8,458**
	VOR/ILS	ARN-58	0	(5,00[illegible]
	IFF Transponder	APX-64 } Same Control	0	651
	Transponder Crypto	KIT-1A } Same Control		
	Antenna Selector	C4808	0	5,087
3	INS	AJN-16 } CCU (C-8586)	2	122
	General Purpose Computer†	AYK-6 } CCU (C-8586)		
	EW Receiver	ALR-62	1	(265)
	IR Receiver	AAR-34	0	1,688
	Jamming Transmitter	ALQ-94	0	2,819
	Chaff Dispenser	ALE-28	0	445
	Auxiliary Flight Reference System	A24G-26C } Separate controls; data combined	0	1,057
	Flight Director System	CPU-76 } Separate controls; data combined		
4	Weapons Control Panel	12E44201-807	0	185
	Navigation Display Panel	ID-1748	0	174
	TF/TA Radar	APQ-146	0	498
	Attack Radar	APQ-144/161	0	2,819
	PAVE TACK	AVQ-26	(No Data Available)	
	Strike Camera	KB-18A	0	2,115

Source: Sacramento ALC AFM66-1 Data (D056)
*( ) Estimated.
**Three months' data.
†In Group 4 avionics; CCU controls INS.

- F-16A -- One remote UHF channel frequency indicator (this also indicates when transmission is on VHF)
- F-111F -- None
- A-10A -- Two VHF controls, one remote UHF channel frequency indicator

Either control or display back-ups are provided for the mission-essential communications in four of the five aircraft. Additional controls in the F-4E and F-15A are not back-ups in the strict sense since they are separate controls for the second subsystem. The F-4E has two ASQ-19B UHF radio set control heads which, because of several modifications, are all that remain of the original installation. It is our understanding that control back-ups are not provided for in the F-111F because of weight and space limitations.

Our investigation showed that in tactical aircraft back-ups (i.e., two controls for the same avionics subsystem) are not normally provided. The reason for this, according to equipment designers, was associated with the usual space and weight limitations in tactical aircraft. Where a second identical control head was available, it was used as a dedicated rather than shared unit. The major exceptions to this apparent design principle are in the control of crypto avionics such as the KY-58 (in which one crypto subsystem might be used to provide secure voice to two different communication subsystems on different frequencies) and the UHF/ADF subsystem (which is controlled by the ARC-164 control head).

There is, however, another perspective regarding back-ups for individual controls -- the "alternate modes of operation" concept mentioned earlier. It can be assumed that a similar avionics subsystem (e.g., UHF rather than VHF) will provide similar capabilities to perform the required avionics function. In our failure analyses we considered these alternate modes of operation. Since the F-111F does not have individual control-head back-ups, use of alternative modes provides a lower failure bound to our results.

4.3.2 Integrated Control Failures

None of the current SAICS applications integrate the unit into an aircraft's architecture in the same manner. This applies to the Air Force's latest implementation plans for the dual-unit KC-135 update and H-X programs, as well as the current implementation of the single A-10 F^3INS control head. Since every major implementation program or study to date has used two or more SAICS-type CNI heads integrated into the aircraft's 1553 avionics architecture, the impact of failure of a single-unit SAICS in tactical aircraft has never been thoroughly analyzed, nor has the impact of combining control and display functions in one integrated unit. Today's tactical air raft with advanced integrated avionics do not have a SAICS-like control head containing a keyboard, a microprocessor, and an alphanumeric display. For example, the F/A-18 cockpit has an up-front CNI keyboard control panel, but any one of its four multifunction displays (MFDs) can be used to obtain readouts similar to those expected from a SAICS unit. Almost every CNI pushbutton control is duplicated on these "smart" MFDs, thus providing complete back-up for both the control and the display functions.

Another impact on SAICS MTBF is that which results from adding system functional control. A SAICS unit can control many different types of avionics systems, as well as subsystem functions. For example, a SAICS unit might be used to control avionics power-up, bus control, system tests, or bus monitoring. Although reliability would undoubtedly decrease with an increase in the number of system functions controlled, failure impact has not been thoroughly analyzed.

As in the case of the individual control-head MTBFs, simplifications are required to analyze system reliability for an integrated control head such as SAICS. We have attempted to account for two principal aspects in our estimates:

- Impact of the loss of only the display on reliability. In most cases failure of the display function does not normally lead to loss of avionics control. Our work concentrated on the control of avionics functions, not display of required information. We recognize, however, that display, using a SAICS, might be as important as control in some cases (e.g., INS position data).
- Impact on SAICS MTBF of the addition of another avionics subsystem control function or a unique subsystem control requirement. In the Army's IACS program, eight different CNI subsystems were controlled. In the A-10, a single F^3INS is controlled (however, such functions as system-level test and bus monitor are also automatically controlled). Since any additional control function is handled primarily through software, failure-data methodology and analysis become difficult.

Since there were no definitive MTBF values currently available in Air Force data suitable for our use, we developed our own SAICS MTBF projections for use in the failure analyses. These MTBFs (Table 4-2) are conservative assumptions based on the actual 2,000-hour test-data MTBF for the overall integrated control system achieved in the IACS prototype program (integrated-control-head MTBF estimated to be 6,000 hours on the basis of MIL-HDBK-217C calculations), the 6,000-hour projection for the 757/767 and KC-135 CDUs, and the 1,400-hour MTBF F^3INS control-head guarantee in the present A-10 program.

Table 4-2. ASSUMED SAICS CDU MTBFs

Group(s)	MTBFs (Hours)	
	Individual SAICS CDUs	With an EW CDU
1	3,000	--
1, 2	2,000	--
1, 2, 3	1,500 each (2 units)	2,000 each (2 SAICS CDUs; 1 EW CDU)
1, 2, 3, 4	1,000 each (2 units)	1,500 each (2 SAICS CDUs); 2,000 for the single EW CDU

Our hypothetical SAICS unit contains a microprocessor, like the one in the A-10 control head, to provide additional system flexibility to accommodate growth and change. We assumed that the controlled avionics subsystems, as well as SAICS, have the capability to interface with a 1553 bus and that the SAICS unit is designed to control up to 14 subsystems.

We decreased the MTBF in proportion to the number of control functions as control of each new trial group was absorbed into the SAICS unit. This decrease would be caused by additional parts (memory), different front panels, and increased usage and complexity. We have also introduced a second (EW) dedicated CDU to control the unique EW subsystems. The reason for the 500-hour increase in MTBF with an EW unit is that three units are used to control the same number of functions previously controlled by two units.

4.3.3 Integrated Control Back-Up Methods

All current implementation schemes for SAICS-type control in a two-seat aircraft use identical dual-redundant units. On the single-seat A-10, there is no back-up; if the control head fails, control of the INS and other system monitoring features is lost. Present-position data continue to be displayed on the HUD, however.

Because of user preference, a manual "reversionary" control such as that shown in Figure 4-4 has usually been implemented in the aircraft integrated avionics architecture as well (the A-10 is an exception to this). A unit of this nature provides a manual means of obtaining a single frequency (normally guard channel for communications) by hardwiring directly to a communications, IFF, or TACAN set. In the Coast Guard HC-130H, manual frequency switching is provided on the integrated control front panel. Depending on the nature of the failure, either communications and IFF back-up or communications back-up alone is provided.

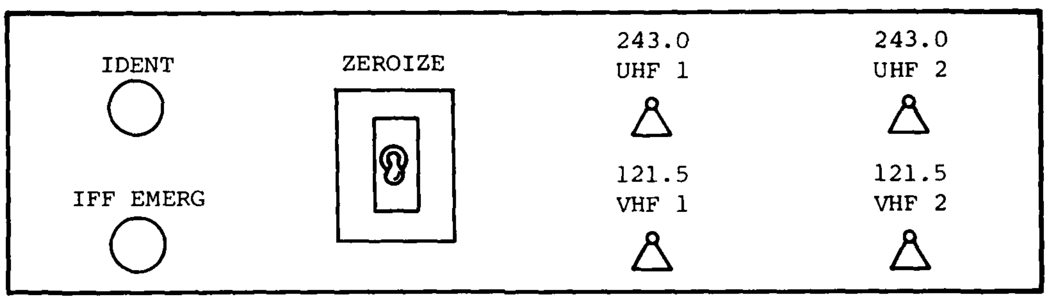


Figure 4-4. CONCEPTUAL SAICS REVERSIONARY CONTROL

An automatic means of back-up was also developed under the IACS program. The bus-to-avionics I/O contained four registers in each CNI avionics interface adapter module. The first two registers held the active and pre-set frequencies for the avionics that the pilot would change as a normal flight progressed. The third register was set to any desired back-up frequency (e.g., home tower, Base Ops), and the fourth was set to the guard frequency. Once set, these latter two frequencies never changed. In case of a control-head failure, the avionics automatically tuned to the first back-up frequency, which could be overridden by a hardwired switch in the cockpit, thus providing two back-up frequencies to the pilot in case of complete failure of the integrated control head. In addition to this automatic radio back-up, the ADF was also placed in the compass mode.

We did not include "reversionary" controls in our SAICS failure analyses, since loss of the integrated control head would degrade mission performance and this type of unit would not provide identical or complete control back-up. In addition, the reliability of a unit of this nature would be very high, resulting in extremely low probability of failure and biased results.

4.4 RESULTS

The results of our criticality-of-failure analyses are shown in Table 4-3. They indicate that the use of a single or dual SAICS-type integrated unit to control the F-111F avionics identified in our trial functional groupings yields a lower probability of failure than the use of existing or updated individual control heads. This is true even when alternate modes of operation are used for the individual controls, except for Group 1. The Group 1 exception is due to the relatively high estimated MTBF (1,700 hours) for the UHF control head, backed up by the HF control, over a relatively short period of time (2.85 hours).

Table 4-3. PROBABILITY OF MISSION FAILURE: F-111F INDIVIDUAL CONTROL HEAD AND SAICS CDU

Group(s)	Individual CDUs with No Back-Up	Individual CDUs with Back-Up*	Number of Assumed SAICS**		
			1	2	3†
1	.0151	.0000+	.0009	-	-
1, 2	.0209	.0056	.0014	-	-
1, 2, 3	.0625	.0402	-	.0000+	.0009
1, 2, 3, 4	.0886	.0669	-	.0000+	.0009
1, 2, 3, 4 (Update††)	.0462	.0435	-	Un-changed	Un-changed

*Alternate modes of operation.
**Groups 1 or 1 and 2: 1 SAICS CDU; other groups: 2 SAICS CDUs.
†Groups 1, 2, 3 or 1, 2, 3, 4: 2 SAICS CDUs, 1 dedicated EW CDU.
††New HF radio, navigation display unit, CCU.

As might be expected, the individual controls without back-up yield a higher probability of failure than the individual controls with back-up. For either of the individual control-head cases, the probability of failure increases as more controls (groups) are added. In addition, the older individual controls experience an increasing probability of failure as they become more complex. As discussed earlier, the update values indicate the increased MTBF due to new HF, navigation display, and CCU controls. The probability of failure should be considerably lower than that of the existing individual controls after these modifications are implemented.

4.5 CONCLUSIONS

We consider the Group 1, 2, and 3 results representative for tactical aircraft with many unique controls such as the F-111. It would be speculative to infer general conclusions from the Group 4 results, which differ among aircraft. Experience with those aircraft which have more highly integrated controls, such as the F-4 or F-15, reenforces the conclusion that failure criticality is not an overriding element in the decision on SAICS. Other conclusions are as follows:

- With the exception of Group 1, our calculated probabilities of mission failure are lower with SAICS. Note that we are dealing with the failures due only to control heads, not the avionics subsystems that they control. As stated previously, individual control-head reliabilities are normally much higher than those of the avionics LRUs that they control.
- These quantitative findings are considered to represent a worst-case situation. They do not, for example, account for the fact that, properly designed, the avionics subsystems continue to operate on the currently selected channel or mode even after a SAICS failure. Therefore, the control-head failure may or may not represent a mission failure in a particular operational environment.
- Relatively small and simple revisionary controls can be installed when SAICS is installed. User views suggest that this would be a prudent option to provide, where space is adequate.

CHAPTER FIVE

COST COMPARISONS OF APPROACHES

5.1 DESCRIPTION OF APPROACHES AND ASSUMPTIONS

This chapter presents a cost comparison of three approaches to integrating old and new avionics control functions into existing cockpits. The following approaches were used:

- Approach I. Continue the use of individual control devices for each old and new avionics function.
- Approach II. Use a unique integrated control system (UICS) for one or more groups of avionics functions for a given type of aircraft.
- Approach III. Use a standardized avionics integrated control system (SAICS) for all aircraft for the functions that are found to be attractive on the basis of Approach II results.

The method used to compare the costs associated with each approach is shown in Figure 5-1. Several ground rules and assumptions associated with our methodology are described in the following subsections.

5.1.1 Architectural Assumptions

A basic assumption underlying the three approaches described is that all old and unreliable avionics subsystems will probably be replaced with new state-of-the-art avionics, with an accompanying change of the corresponding control heads. For Approach I, it is assumed that each existing avionics control will be replaced once, resulting in candidate aircraft with a complete exchange of individual control heads. For Approaches II and III, it is assumed that control functions can be integrated when some of the existing avionics are replaced and new integrated control heads, which replace the existing individual control heads in either a unique fashion (Approach II) or a standardized fashion (Approach III), are added. We also made the following assumptions:

- By 1985 current concepts for avionics integrat :ontrols have matured. Group B integrated CDU development (either SA : or UICS) and testing is complete and R&D costs are sunk. However, engineering integration

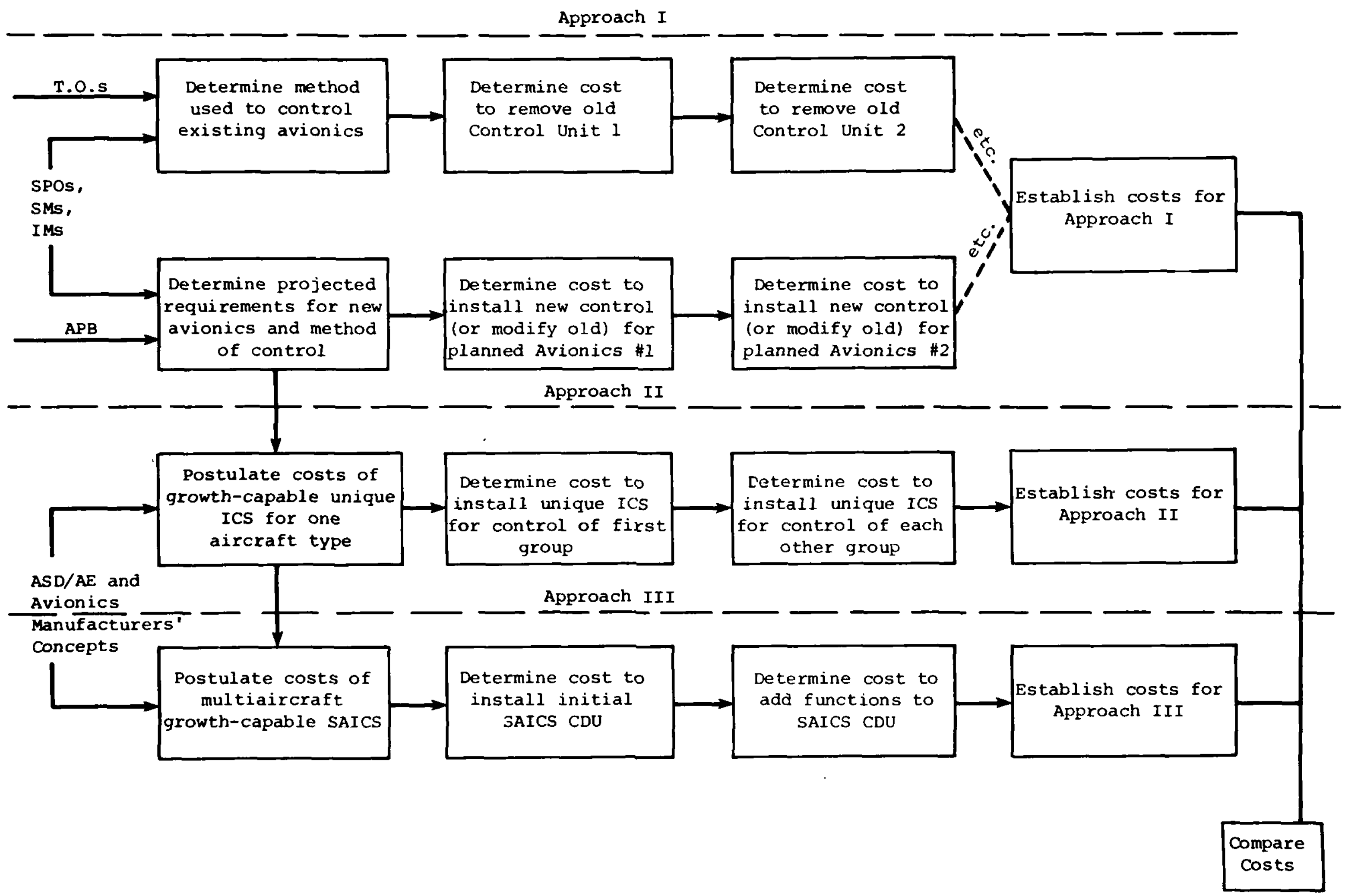


Figure 5-1. COST COMPARISON METHOD

costs for CDU Group A kits and preproduction prototyping, as well as testing costs, have been included in our calculations.

- For the UICS, no software, firmware, hardware, or interface standardization, other than 1553, is mandated. Aircraft-unique memory growth for new functions is provided, but unique ICS software costs for control of new functions are charged to the avionics subsystem program and are not included in our costs.
- For the SAICS, the software, firmware, hardware, and interface standardization is directed. A modular design approach is followed, wherein an additional group of control functions can be added by changing the front-panel keyboard or memory module. Enough SAICS memory is available to control up to 14 CNI subsystems in any candidate aircraft. Software costs for control of new functions are charged to the avionics subsystem program and are not included in the analyses.
- A reversionary control unit is installed as back-up to a UICS or SAICS unit and is costed as a separate control panel.

5.1.2 Economic Assumptions

We made the following economic assumptions:

- All costs are calculated in constant FY 1980 dollars.
- Installation labor costs of $50 per hour in FY 1980 dollars are used. This rate is assumed to include direct labor, overhead, general and administrative fees, and profit. It also includes a factor to account for the manufacturing labor support required to complete the installations.
- Only system investment costs are addressed. Because of the inherently higher MTBFs of CDUs, the operation and support costs of individual and integrated controls were assumed to be comparable. System investment costs include the following:
    - Group A modification costs -- associated with modifying the aircraft cockpit panels and consoles to install the new control devices.
    - Group B costs -- associated with procuring the individual and integrated avionics subsystem controls.
    - Installation labor costs -- associated with installing or removing the avionics subsystem controls in the aircraft cockpit.

(Note: The detailed methodology used to establish both the Group A modification and installation labor costs are contained in our avionics installation [AVSTALL] cost model,* which is discussed in greater detail in Appendix C.)

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*ARINC Research Publication 1727-04-1-1959, *Avionics Installation (AVSTALL) Cost Model for User Equipment of NAVSTAR Global Positioning System*, June 1979.

5.1.3 Approach I Modification Assumptions

The cost of replacing existing controls and adding new ones was calculated by using the equations identified in Appendix C. We assumed that a new control would utilize the same space as before but would interface with a 1553 multiplexer bus. For the planned avionics, we made the following assumptions:

- Group 1 - Communications and Communications Crypto
  - SEEK TALK. The ARC-164 control will be replaced with little change to the existing wiring (no direct 1553 interface).
  - SINCGARS. A new control will be required for the A-10A aircraft that receive SINCGARS.
  - Adaptive HF. A new control, with the same weight and unit cost as the ARC-190 HF, will be installed to control the A-10A adaptive HF functions.
- Group 2 - Radio Navigation (R-NAV) and Identification
  - GPS. While it is possible that a new control panel will be needed in the F-111F and other aircraft, we assumed for our cost analyses that all of the GPS controls would be modifications to existing equipment. We also assumed that the TACAN would not be removed upon installation of GPS.
  - JTIDS. The F-16A will require changes similar to those planned for the F-15A. Because of the complex nature of the F-15A avionics architecture and lack of detailed data, we have excluded the costs of installing the new armament control system (ACS) display, symbol generator, and digital data units, and the costs of modifying the existing ACS, central computer, radar warning receiver, and radar set, all of which will be required when JTIDS is installed in the F-15A.
  - MLS. A long transition period is required for MLS; both ILS and MLS will therefore be available to ensure worldwide coverage. We included the cost of adding an MLS control unit and did not include the cost of removing the ILS.
  - NATO IFF. The NATO IFF will replace the functions of the Mark XII IFF transponder and interrogator. In the F-16A, we assumed that the existing APX-101 control would be replaced and a new control would also be added to provide an interrogator capability that does not exist today.
- Group 3 - INS and EW. For our additional new Group 3 avionics, we included only one additional control for cost-comparison purposes. Both the F^3INS for the F-111F and the ALR-69 for the A-10A are to be installed before 1985 -- too early to be used in our comparisons. The ALQ-165 ECM set control for the F-16A was costed as a new item.

- Group 4 - Mission-Unique. For the post-1985 planned Group 4 avionics, available engineering data were insufficient to provide quantitative cost comparisons. We did calculate the cost of modifying the F-111F weapons panel to control Wasp.

5.2 COST CALCULATIONS

5.2.1 Approach I

In Approach I, costs of removing and replacing individual controls for both existing and planned avionics were calculated for the five candidate aircraft. Calculation of these costs by use of the AVSTALL model required a knowledge of the Group B control costs and unit weights. This information is presented in Table 5-1.

Our Approach I results are presented in Tables 5-2 and 5-3. The Table 5-2 F-111F Approach I results are shown separately so that they can be compared with F-111F costs compiled for Approaches II and III. The Table 5-3 Approach I results for all candidate aircraft costs are shown only for Groups 1, 2, and 3, because available data were insufficient to provide useful results for Group 4 control costs.

5.2.2 Approach II

For Approach II, unique integrated control system (ICS) CDU and reversionary control costs and weights were required for all aircraft. The Table 5-4 Group B unique ICS CDU and reversionary control panel estimates were developed from our compiled data. The CDU estimates are based on the actual costs for the A-10 F^3INS CDU ($13,000 for the first 263 aircraft, $9,080 for the next 233), the approximate cost for the SRR CDU ($9,500), the IACS CDU cost estimate ($5,000) and the cost estimate used in the KC-135 update study ($8,000). Our weight estimates are also based on these programs and are needed to calculate Group A and installation costs. The F-111F unique ICS CDU costs are lower than those of the remaining candidate aircraft, because the CDU would control fewer functions.

Costs for Approach II were computed in two ways: (1) by assuming that all of the existing individual control heads would be removed at one time (saving labor hours), and (2) by assuming that the individual controls would be removed one at a time. Although it is improbable that either of these modification scenarios would take place, the results bound our costs within the two extremes.

Our calculated costs for Approach II are shown in Tables 5-5 and 5-6. Table 5-5 presents the F-111F data, and Table 5-6 presents the total for all five candidate aircraft. Included in both these tables are our calculated costs for the reversionary control panel discussed earlier.

Table 5-1. TYPICAL EXISTING AND PLANNED INDIVIDUAL CDU CHARACTERISTICS

Group	Avionics	System	Candidate Aircraft	Group B Unit Cost ($ Thousands)	Weight (Pounds)	Size (H × W × D in Inches)	Source
1	UHF	ARC-164	All aircraft	5.000	4.32	4.875 × 5.75 × 5.34	WRALC Item Manager
	VHF-AM/FM	ARC-186	F-15A, F-4E	1.000	2.50	2.25 × 5.75 × 4.9	WRALC Item Manager
	UHF Crypto	KY-58	F-111F	0.350	2.00*	3.5 × 5.75 × TBD	KC-135 avionics system update study
	HF	ARC-190	F-111F	0.941	1.50	2.62 × 5.75 × 4.5	KC-135 avionics system update study
	HF Crypto	KY-75	F-111F	1.000	2.00*	3.5 × 5.75 × TBD	KC-135 avionics system update study
	VHF-FM	SINCGARS	A-10A	0.200	4.00	4.0 × 5.75 × TBD	CORADCOM Program Manager
	Adaptive HF	TBD	A-10A	0.941*	1.50*	TBD	Engineering estimate
2	TACAN	ARN-118	F-111F	1.657	2.00	5.16 × 5.75 × 3.0	WRALC Item Manager
	VOR/ILS	ARN-127	F-15A, F-111F	0.300	2.00	2.25 × 5.75 × 6.0	H-X Study
	Antenna Selector	TBD	All aircraft	1.000*	1.00*	1.125 × 5.75 × TBD	Engineering estimate
	IFF Transponder	APX-101	F-111F	0.548	2.75	5.75 × 5.25 × 3.09	WRALC Item Manager
	GPS	TBD	All aircraft, XF4-E	8.056**	6.40	TBD	ARINC Research Santa Ana Office
	JTIDS	TBD	F-16A, F-15A	2.000/1.500	4.00/2.00	TBD	MDAC Report ESD-TR-78-149
	MLS	TBD	All aircraft	1.835*	2.00*	TBD	Engineering estimate
	NATO IFF	TBD	All aircraft	0.548/1.000*	2.75/2.00*	TBD	Engineering estimate
3	EW Receiver	ALR-69	A-10A, F-111F	0.780	2.00	2.625 × 5.75 × 5.75	WRALC Item Manager
	IR Receiver	AAR-34	F-111F	1.000*	2.00*	2.625 × 5.75 × TBD	Engineering estimate
	Jamming Transmitter	ALQ-131	F-111F	0.968	2.00	2.625 × 5.75 × 5.75	WRALC Item Manager
	TEWS	ALQ-165	F-16A	1.380/1.386	2.40/0.60	4.5 × 5.75 × 5.2/ 1.125 × 5.75 × 5.2	WRALC Item Manager
	Chaff Dispenser	ALE-28	F-111F	0.800*	2.00*	4.125 × 5.75 × TBD	Engineering estimate
4	CCU (INS)	1D-1748/AYK	F-111F	19.000†	11.01	7.875 × 7.2 × TBD	SMALC Item Manager
	Navigation Display	C-8586	F-111F	34.000†	26.81	7.875 × 8.8 × TBD	SMALC Item Manager
	Weapons Control	12E44201-807	F-111F	25.000†	18.02	11.7 × 7.2 × TBD	SMALC Item Manager

*Estimated.
**Cost of a new panel.
†Cost to modify panel.

Table 5-2. APPROACH I: POST-1985 REPLACEMENT/ADDITION/MODIFICATION COSTS FOR F-111F INDIVIDUAL CONTROLS (84 AIRCRAFT)

Group	Avionics Type	Old/New Subsystem	Task	System Investment Costs ($ Thousands)				Cumulative Totals
				Group A	Group B	Installation	Total	
			Existing Controls					
1	UHF	ARC-164/SEEK TALK	Remove and replace	48	420	18	486	486
			Subtotal	48	420	18	486	
2	TACAN	ARN-84/ARN-118	Remove and replace	95	139	229	463	2,085
	VOR/ILS	ARN-58/ARN-127	Remove and replace	95	25	229	349	
	Antenna Selector	C-4808/TBD	Remove and replace	95	84	229	408	
	IFF Transponder	APX-64/APX-101	Remove and replace	104	46	229	379	
			Subtotal	389	294	916	1,599	
3	EW Receiver	ALR-62/ALR-69	Remove and replace	28	66	30	124	3,413
	IR Receiver	AAR-34/TBD	Remove and replace	95	84	229	408	
	Jamming Transmitter	ALQ-94/ALQ-131	Remove and replace	95	81	229	405	
	Chaff Dispenser	ALE-28/ALE-40	Remove and replace	95	67	229	391	
			Subtotal	313	298	717	1,328	
4	St ike Camera	KB-18A/TBD	Remove and replace	95	84	229	408	3,821
			Subtotal	95	84	229	408	
			New Avionics					
1	None Planned	N/A	N/A	N/A				486*
2	GPS	--/TBD	Modify panels**	56	272	60	388	3,423*
	MLS	--/TBD	Add	81	154	336	571	
	NATO IFF	APX-101/TBD	Remove and replace	104	46	229	379	
			Subtotal	241	472	625	1,338	
3	None Planned	N/A	N/A	N/A				4,751*
4	Wasp	12E44201/--	Modify weapons panel	28	2,100	30	2,158	7,317*
			Subtotal	28	2,100	30	2,158	

*Totals include existing and new avionics controls.
**Assumes modification of CCU and navigation display panels.

Table 5-3. APPROACH I: POST-1985 REPLACEMENT/ADDITION/MODIFICATION COSTS FOR ALL CANDIDATE AIRCRAFT INDIVIDUAL CONTROLS (2166 AIRCRAFT)

Group*	Avionics	Cost by Aircraft Type ($ Thousands)						
		F-16A	F-15A	F-4E	A-10A	F-111F	Total	Cumulative Total
	Replacement of Existing Controls							
1	UHF	3,551	3,230	2,703	3,303	486	13,273	16,508
	VHF-AM/FM	0	1,309	1,926	0	0	3,235	
	Total	3,551	4,539	4,629	3,303	486	16,508	
2	VOR/ILS	1,448	821	1,182	1,372	349	5,172	42,293
	Antenna Selector	1,912	1,032	1,533	1,803	408	6,688	
	IFF Transponder	1,640	912	1,330	1,552	379	5,813	
	TACAN	2,348	1,230	1,863	2,208	463	8,112	
	Total	7,348	3,995	5,908	6,935	1,599	25,785	
3	EW Receiver	732	361	569	684	124	2,470	61,488
	Jamming Transmitter	1,891	1,022	1,517	1,783	405	6,618	
	Chaff Dispenser	1,779	972	1,432	1,680	391	6,254	
	IR Receiver	1,912	0	1,533	0	408	3,853	
	Total	6,314	2,355	5,051	4,147	1,328	19,195	
	Addition of New Controls							
1	VHF-FM	0	0	0	1,989	0	1,989	20,551
	Adaptive HF	0	0	0	2,054	0	2,054	
	Total	0	0	0	4,043	0	4,043	
2	GPS	2,478	1,227	0	2,404	388	6,497	84,026
	JTIDS	7,375	4,012	0	0	0	11,387	
	MLS	2,855	1,511	2,276	2,688	571	9,901	
	NATO IFF	4,025	1,588	2,361	1,552	379	9,905	
	Total	16,733	8, 8	4,637	6,644	1,338	37,690	
3	ECM Set	4,119	0	0	0	0	4,119	107,340
	Total	4,119	0	0	0	0	4,119	

*Group 4 omitted because of lack of detailed data.

Table 5-4. ESTIMATED AVERAGE COSTS AND WEIGHTS FOR GROUP B UNIQUE ICS CDU AND REVERSIONARY CONTROL				
Group	F-111F Unique ICS CDU		All Other Unique ICS CDUs	
	Cost* ($ Thousands)	Weight (Pounds)	Cost* ($ Thousands)	Weight (Pounds)
Unique ICS CDU				
1	9	10	10	10
1,2	11	11**	11	11**
1,2,3	13	11	14	11
1,2,3,4	15	11	16	11
Reversionary Control Panel				
1	0.5	1.0	0.75	1.0
1,2,3,4	0.7	1.5	1.25	1.5

*The cost difference between groups is due to added memory for the performance of additional functions.

**The largest functional increase occurs between Groups 1 and 2; the added weight is for additional memory and a new front panel.

5.2.3 Approach III

For Approach III, the SAICS CDU and reversionary control costs and weights were required for all aircraft. Our Group B SAICS CDU and reversionary control panel estimates are shown in Table 5-7. The slight difference between the unique ICS costs presented in Table 5-4 and SAICS CDU costs is due primarily to the learning-curve effects of quantity buying for SAICS. This advantage is nearly offset, however, by the additional costs attributed to the increased SAICS memory, since a common unit would need the built-in capability to control more avionics functions. We also assumed that the reversionary control panel would be hand-tailored for each aircraft and use the same estimates developed for the unique ICS.

The total costs for Approach III are presented in Tables 5-8 and 5-9. Table 5-8 presents the F-111F data, and Table 5-9 is the total for all five candidate aircraft. Included in these totals are our calculated costs for the reversionary panel discussed earlier.

As in the case of Approach II, costs for Approach III were computed by assuming that all of the individual control heads would be removed at one time and also by assuming that the individual controls would be removed one at a time.

Table 5-[illegible]. APPROACH II: COST OF REMOVING EXISTING F-111F CONTROLS AND ADDING A UNIQUE ICS CDU AND REVERSIONARY CONTROL

Group	Action	Cost of Simultaneous Addition and Removal ($ Thousands)	Cost of Separate Addition and Removal ($ Thousands)
1	Remove Existing Individual Controls	1,050	1,089
	Add Unique ICS (1)	1,586	1,586
	Add Reversionary Control	108	108
	Total	2,744*	2,783*
1,2	Remove Existing Individual Controls	409	672
	Add Unique ICS (1)	1,794	1,794
	Add Reversionary Control	125	125
	Total	2,328	2,591
1,2,3	Remove Existing Individual Controls	593	1,120
	Add Unique ICS (2)	3,573	3,573
	Add Reversionary Control	125	125
	Total	4,291	4,818
1,2,3,4	Remove Existing Individual Controls	759	1,568
	Add Unique ICS (2)	3,913	3,913
	Add Reversionary Control	125	125
	Total	4,797	5,606

*Includes cost of moving TACAN for Group 1 only. Not required to be moved in other group combinations.

Table 5-6. APPROACH II: COST OF REMOVING EXISTING CANDIDATE AIRCRAFT CONTROLS AND ADDING A UNIQUE ICS CDU AND REVERSIONARY CONTROL

Group*	Action	F-16A	F-15A	F-4E	A-10A	F-111F	Total
Cost of Simultaneous Addition and Removal ($ Thousands)							
1,2	Remove Existing Individual Controls	1,857	1,198	1,695	2,121	409	7,280
	Add Unique ICS (1)	11,219	5,542	8,729	10,497	1,794	37,781
	Add Reversionary Control	1,084	527	840	1,013	125	3,589
	Total	14,160	7,267	11,264	13,631	2,328	48,650
1,2,3	Remove Existing Individual Controls	2,408	1,511	2,278	2,617	593	9,407
	Add Unique ICS (2)	23,778	11,504	18,377	22,208	3,573	79,440
	Add Reversionary Control	1,084	527	840	1,013	125	3,589
	Total	27,270	13,542	21,495	25,838	4,291	92,436
Cost of Separate Addition and Removal ($ Thousands)							
1,2	Remove Existing Individual Controls	3,192	2,041	3,024	3,752	672	12,681
	Add Unique ICS (1)	11,219	5,542	8,729	10,497	1,794	37,781
	Add Reversionary Control	1,084	527	840	1,013	125	3,589
	Total	15,495	8,110	12,593	15,262	2,591	54,051
1,2,3	Remove Existing Individual Controls	4,560	2,842	4,536	5,054	1,120	18,112
	Add Unique ICS (2)	23,778	11,504	18,377	22,208	3,573	79,440
	Add Reversionary Control	1,084	527	840	1,013	125	3,589
	Total	29,422	14,873	23,753	28,275	4,818	101,141

*Group 4 omitted because of lack of detailed data.

Table 5-7. ESTIMATED AVERAGE COSTS AND WEIGHTS FOR GROUP B SAICS CDU AND REVERSIONARY CONTROL		
Group	Cost ($ Thousands)	Weight (Pounds)
SAICS CDU		
1	8	10
1,2	10	11
1,2,3	12	11
1,2,3,4	14	11
Reversionary Control Panel		
1	0.75	1.0
1,2,3,4	1.25	1.5

5.3 SUMMARY RESULTS

The results of our cost-benefit analyses, summarized in Table 5-10, indicated that after the planned new avionics are installed, the use of an integrated cockpit control such as a SAICS CDU produces distinct cost savings in comparison with the use of individual controls.

For our integrated Approaches (II and III), a cost-estimate range was calculated. The lower bound of this range is the cost of removing the individual controls and adding one or two integrated control units at the same time. The upper bound is the cost of adding integrated controls and then removing individual controls separately (the problem of sufficient space has not been addressed for this case).

The following subsections present comparisons of Approach I versus Approaches II and III for the F-111F and Approach I versus Approaches II and III for all candidate aircraft.

5.3.1 Approach I Versus Approaches II and III for the F-111F

Figure 5-2 shows that the addition of either a unique ICS or a SAICS to control the existing F-111F avionics subsystems costs more than replacement of the existing individual controls. (However, the integrated CDU has the potential for growth, while the individual control hardware does not.)

Table 5-8. APPROACH III: COST OF REMOVING EXISTING F-111F CONTROLS AND ADDING A SAICS CDU AND REVERSIONARY CONTROL

Group	Action	Cost of Simultaneous Addition and Removal ($ Thousands)	Cost of Separate Addition and Removal ($ Thousands)
1	Remove Existing Individual Controls	1,050	1,089
	Add SAICS (1)	1,502	1,502
	Add Reversionary Control	129	129
	Total	2,681*	2,720*
1,2	Remove Existing Individual Controls	409	672
	Add SAICS (1)	1,703	1,703
	Add Reversionary Control	172	172
	Total	2,284	2,547
1,2,3	Remove Existing Individual Controls	593	1,120
	Add SAICS (2)	3,377	3,377
	Add Reversionary Control	172	172
	Total	4,142	4,669
1,2,3,4	Remove Existing Individual Controls	759	1,568
	Add SAICS (2)	3,221	3,221
	Add Reversionary Control	172	172
	Total	4,152	4,961

*Includes cost to move TACAN for Group 1 only.

Table 5-9. APPROACH III: COST OF REMOVING EXISTING CANDIDATE AIRCRAFT CONTROLS AND ADDING A SAICS CDU AND REVERSIONARY CONTROL

Group	Action	F-16A	F-15A	F-4E	A-10A	F-111F	Total
Cost of Simultaneous Addition and Removal ($ Thousands)							
1,2	Remove Existing Individual Controls	1,857	1,198	1,695	2,121	409	7,280
	Add SAICS (1)	9,880	4,929	7,713	9,252	1,703	33,477
	Add Reversionary Control	1,084	527	840	1,013	172	3,636
	Total	12,821	6,654	10,248	12,386	2,284	44,393
1,2,3	Remove Existing Individual Controls	2,408	1,511	2,278	2,617	593	9,407
	Add SAICS (2)	21,113	10,287	16,356	19,731	3,377	70,864
	Add Reversionary Control	1,084	527	840	1,013	172	3,636
	Total	24,605	12,325	19,474	23,361	4,142	83,907
Cost of Separate Addition and Removal ($ Thousands)							
1,2	Remove Existing Individual Controls	3,192	2,041	3,024	3,752	672	12,681
	Add SAICS (1)	9,880	4,929	7,713	9,252	1,703	33,477
	Add Reversionary Control	1,084	527	840	1,013	172	3,636
	Total	14,156	7,497	11,577	14,017	2,547	49,794
1,2,3	Remove Existing Individual Controls	4,560	2,842	4,536	5,054	1,120	18,112
	Add SAICS (2)	2,113	10,287	16,356	19,731	3,377	70,864
	Add Reversionary Control	1,084	527	840	1,013	172	3,636
	Total	26,757	13,656	21,732	25,798	4,669	92,612

Table 5-10. INTEGRATED-CONTROL COST SAVINGS				
Group(s)	F-111F		All Candidate Aircraft	
	Approach II	Approach III	Approach II	Approach III
1	No	No	No	No
1, 2	Yes*	Yes*	Yes*	Yes*
1, 2, 3	Yes**	Yes**	Yes*	Yes*
1, 2, 3, 4	Yes*	Yes*	N/A	N/A

*Provided all planned avionics subsystems are installed.
**Provided all planned avionics subsystems are installed and existing controls are not removed separately.

For Group 1, the cost of Approaches II and III is significantly higher than the cost of Approach I. More than 30 percent (about $0.9 million) of the Approach II and III costs is incurred in moving the TACAN control to provide enough space for installation of the integrated CDU. For the F-111F, it does not appear to be cost-beneficial merely to exchange the individual Group 1 communications controls for an integrated control.

For Groups 1 and 2, the cost of replacing the existing controls is slightly lower than the cost of adding a single integrated CDU (approximately $300,000). However, when the planned new avionics are added in the out-years, the cost of Approach I increases to $3.4 million, which is 48 percent more than the cost of Approaches II or III.

Two unique ICS or SAICS CDUs are required to control the old and new avionics functions of Groups 1, 2, and 3 or 1, 2, 3, and 4. The cost of the second CDU causes the Approach II and III costs to be slightly higher than the Approach I cost for replacement of existing controls (about $3.4 million versus $4.2 million). This disadvantage is offset when the costs of the planned individual controls are included.

As the number of existing avionics subsystems being controlled by the integrated CDU increases, so does the variation between the upper and lower bounds of the Approach II and III costs, because of the greater reduction in labor achieved by removing several controls at one time instead of individually. The small differences in Approach II and Approach III unique ICS and SAICS costs can be attributed to differences in integrated CDU Group B costs (Tables 5-4 and 5-7); the bounded costs are the same.

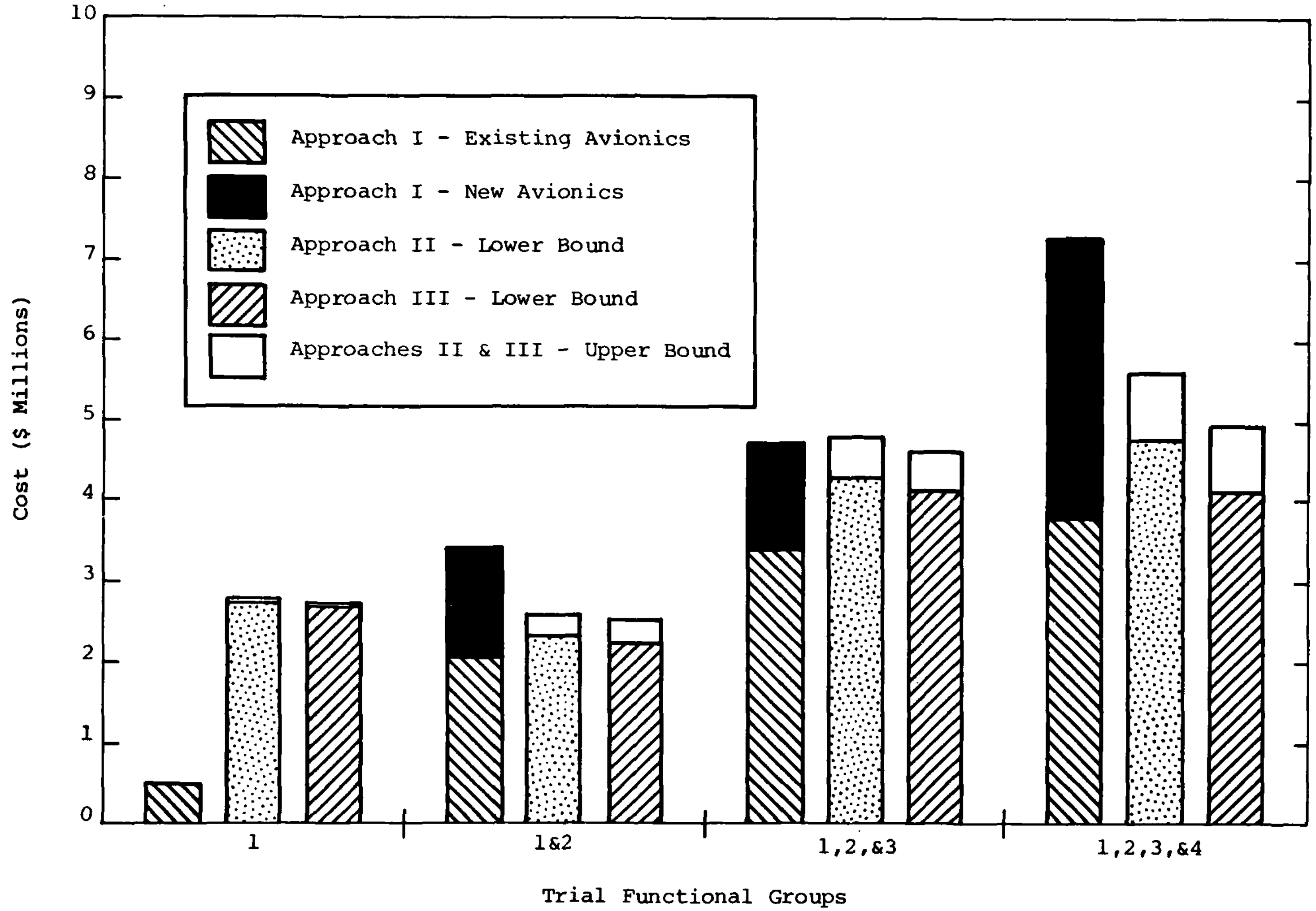

Figure 5-2. F-111F COST COMPARISON FOR APPROACHES I, II, AND III

As stated previously, the pre-1985 F-111F new installations -- namely, the UHF and HF cryptos, HF radio, F^3INS, and CCU and navigation display panel modifications -- have not been considered in this cost-benefit comparison. If plans were made to install a unique ICS or SAICS in the F-111F by 1985, the currently planned modification programs for individual control of the cryptos, HF radio, and INS could be canceled and these individual control functions could be absorbed by one or more integrated control heads. The modification of the CCU and navigation display panels would undoubtedly continue, since they also are part of an earlier planned and approach computer update program. With either Approach II or Approach III, using an integrated CDU to control the new F-111F cryptos and HF radio would save more than $1.3 million in investment costs.

5.3.2 Approach I Versus Approaches II and III for All Candidate Aircraft

Figure 5-3 illustrates the results of Approaches I, II, and III, Groups 1 and 2 and Groups 1, 2, and 3, for the five candidate aircraft. For Groups 1 and 2, Approaches II and III produce the greatest cost savings when the post-1985 new avionics are installed. As in the case of the F-111F, it would be beneficial to start installing SAICS CDUs as early as possible, before any planned new avionics are installed. This one-time installation would provide the capability subsequently to remove additional individual controls as they become superseded, since the SAICS memory capacity would be available to integrate each individual control function into the CDU at the appropriate time (i.e., when updated avionics are introduced or existing controls become unusable).

Since the SAICS is a common unit, it must be able to control all of the possible Group 1, 2, and 3 avionics functions. In Approach I, Groups 1, 2, and 3, we identified 17 different types of avionics subsystems that either exist or will be installed in the candidate aircraft. However, the "normal" tactical aircraft will control only 8 of these 17 avionics, at an average cost of about $5,000. This average includes the cost of the A-kit, Group B control hardware, cables, and installation labor. Therefore, when we compare Approach I with Approach III, we are comparing differing capabilities. For this reason, and because two SAICS units per aircraft are required for Groups 1, 2, and 3, Approach III costs for existing avionics are about $22 million higher than Approach I costs. This cost comparison does not take into account the weight or space savings considered for the F-111F in Chapter Three, nor any judgments concerning whether there would be enough room for the new avionics later, if Approach I is pursued.

Replacing the Group 1 and 2 individual controls with an integrated CDU for our candidate aircraft produces eventual cost savings when the new functions are added after 1985. However, for Groups 1, 2, and 3 the cost savings may not be as attractive as for Groups 1 and 2, since two CDUs are needed. The economic attractiveness of adding Group 3 functions to existing tactical aircraft should therefore be considered on a case-by-case basis.

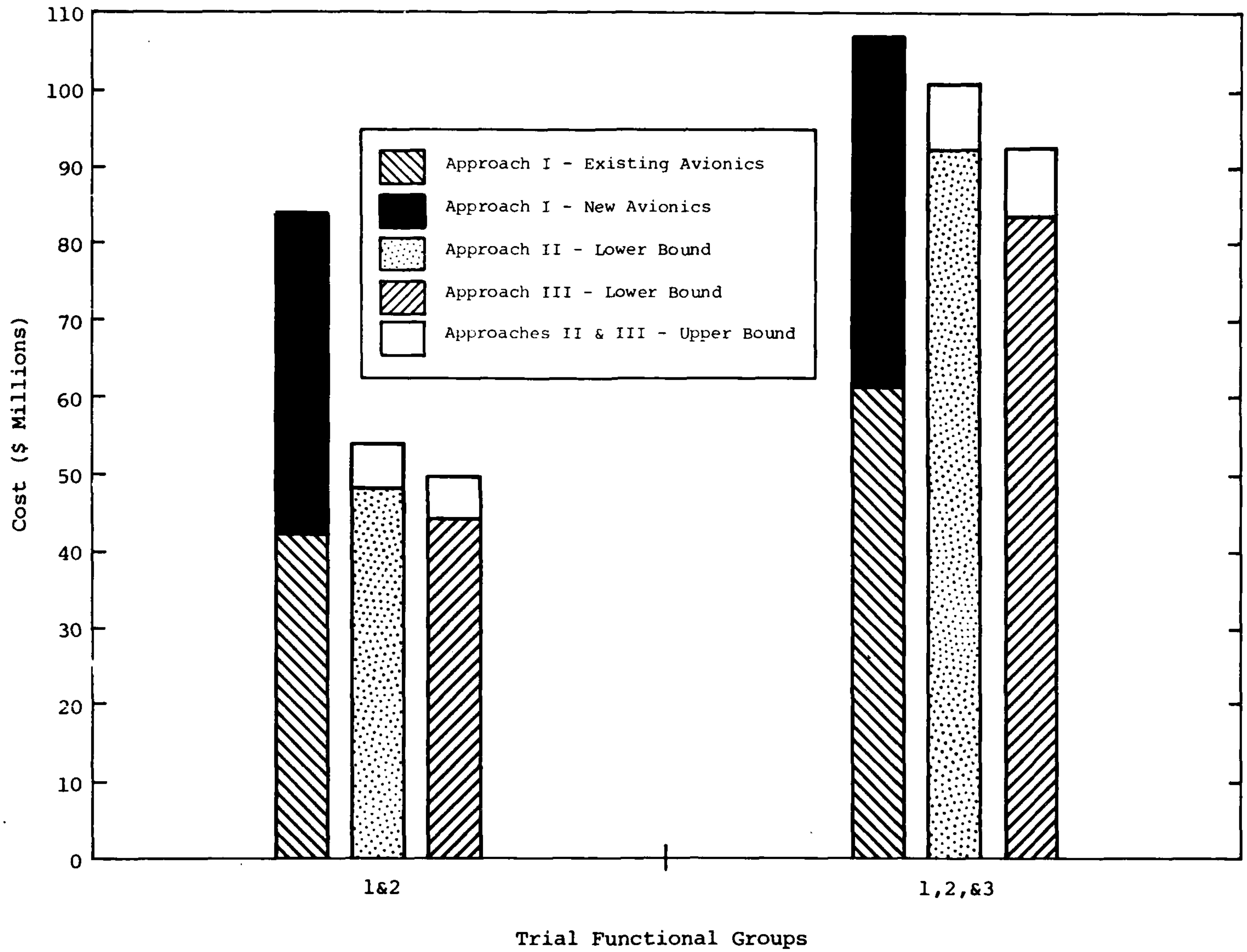

Figure 5-3. ALL-CANDIDATE-AIRCRAFT COST COMPARISON FOR APPROACHES I, II, AND III

It is difficult to predict what impact the introduction of O&S costs would have on the attractiveness of Approach III. On one hand, the greater commonality of parts, maintenance procedures, and support equipment tends to favor the general-purpose system. On the other hand, the greater complexity of the system makes maintenance a more difficult task. The future support concept must be known before qualitative or quantitative assessments can be made. In the newer digital systems, software costs rather than hardware costs are becoming the LCC drivers. Software development and support costs have not been explicitly treated in our analyses. They require further investigation of the higher-level integration approaches considered for application.

Our analyses do not provide a convincing case for SAICS investment from a purely economic point of view, even though they highlight the economic advantages of an integrated CDU. The benefits are not immediate, and many of the costs have been estimated. However, in combination with the weight, power, space, and human-factors considerations, the SAICS concept merits continued consideration.

CHAPTER SIX

DETERMINATION OF CANDIDATE FUNCTIONAL GROUPINGS

6.1 APPROACH

Our trial functional groupings were established for convenience of reference into traditional categories of functions, e.g., communications, identification, and radio navigation. To some extent, our cost-benefits analysis remains valid for substitution among groups. For example, one cost avoidance of installing several inexpensive communications controllers from Group 1 is equal to that of avoiding the requirement of installing a complex EW controller from Group 3. The determination of which standard functions should be implemented for a SAICS cannot be answered on the basis of the cost analysis alone.

The initial implementation of SAICS should have a set of standard control functions common to much of the Air Force, and a potential for growth for those functions not in wide use. To provide insight into the question as to which common control functions should be a part of every SAICS CDU and which are more unique, we developed a ranking technique for the relative attractiveness of each function within the trial groupings for standardized treatment. This ranking technique follows that employed by ARINC Research on an earlier Air Force avionics standardization study,* but modifies several categories.

We employed the five criteria discussed in Sections 6.1.1 through 6.1.5.

6.1.1 Architecturally Well Defined

An existing or planned GFE program is in progress for the avionics function. This includes equipments that have evolved into de facto standards because of their widespread use among multiple aircraft types. The existence of a planned or de facto standard indicates that the avionics function is architecturally well defined and, therefore, its control functions are reasonably stable. Our source for this determination was the March 1978 report cited in the previous document.

**Air Force Avionics Standardization: An Assessment of System/Subsystem Opportunities*, ARINC Research Publication 1910-13-2-1722, March 1978.

6.1.2 Significant Economic Impact

There is wide use of the avionics function within the Air Force. High use in our previous analysis was defined to be in excess of 4,000 units in the force by 1985 -- about 40 percent of the Air Force fleet. Thus a significant potential for cost avoidance would exist if a standard for controlling this function were available. Our source of information is the 1980 issue of the Avionics Planning Baseline document.

6.1.3 Low Technical Risk

We did not investigate a detailed technical implementation approach for each of the avionics functions; however, we reasoned that if a function has been previously integrated, together with others, in a general-purpose control system, there are sufficient technical data on integration problems and human-factors aspects to reduce the technical risk for an improved system. Our source for this information is the summary table in Chapter Two.

6.1.4 Low Safety Criticality

Our quantitative analysis of the control-head failure criticality provided in Chapter Four showed uniformly low failure rates for the control heads. Therefore, we have used the more restrictive definition of safety criticality employed by the San Antonio ALC.* In assessing safety criticality for avionics systems, the Air Force assigns low safety criticality to communications and identification equipment and high criticality to navigation and flight control equipment. The integration of many safety-critical functions into a single control is potentially hazardous. Thus low safety criticality is an important criterion for SAICS candidate functions.

6.1.5 Low-Usage Factor

The control of too many high-usage functions by a single unit presents a potential human-factors problem. Functions used at nonconflicting times of the flight profile are ideal complementary functions for an integrated control. An example of the latter is the use of IFF (in the cruise and mission portions of the flight) and the use of ILS (during landing). We employed as our criterion a mean mission usage of 0.5 or less, as derived from the mission profiles in Appendix B. For those avionics units not addressed in Appendix B, we inferred a usage factor based on similarity of function. We used the IFF transponder usage factor for the NATO IFF.

6.2 RESULTS

The results of our ranking of the suitability of the candidate functions for integrated controls are shown in Table 6-1. We have included

**Development of USAF Flight Safety Model,* ARINC Research Publication C54-01-1406, September 1975.

Table 6-1. SUITABILITY RANKING OF CONTROL FUNCTIONS

Avionics Ranking	Architecturally Well Defined	Significant Economic Impact	Low Technical Risk	Low Safety Criticality	Low Usage Factor	Existing or De Facto GFE Avionics Equipment Standard
1. TACAN	X	X	X		X	ARN-118
2. IFF Transponder	X	X	X	X		APX-100/101 (Control head is the same)
3. ILS	X	X	X		X	ARN-108
4. Crypto (1)	X	X	X	X		KY-58/75
5. Crypto (2)	X	X	X	X		KY-58/75
6. UHF (1)	X	X	X	X		ARC-164
7. VHF (1)	X	X	X	X		ARC-186
8. HF (1)	X	X	X	X		ARC-190
9. ADF	X	X	X		X	OA-8639
10. Antenna Select		X	X	X	X	---
11. INS	X	X	X		X	F^3 INS
12. EW (1)	X	X		X	X	ALR-46
13. SMS		X	X	X	X	MIL-STD-1760 architectures planned for new systems such as AMRAAM, WASP, LANTIRN
14. IFF Interrogator	X		X	X		APX-76
15. VHF (2)	X		X	X		ARC-186
16. VOR/DME	X		X		X	Often combined with ILS
17. LORAN	X		X		X	ARN-109
18. UHF (2)	X		X	X		ARC-164
19. VHF (2)	X		X	X		ARC-186
20. HF (2)	X		X	X		ARC-190
21. Omega	X				X	ARN-120
22. JTIDS		X		X		Future joint standard
23. MLS		X			X	Future joint standard
24. NATO IFF		X		X		Future joint standard
25. EW (2)				X	X	---
26. Doppler	X				X	Communication strategic doppler

only subsystems that meet two or more of our suitability criteria. We have added several subsystems, such as Omega and LORAN, that were not installed in the tactical aircraft candidates addressed in our study but are found in other parts of the fleet. We have also recognized those avionics subsystems which are redundantly installed in some aircraft, since a second controller for primary and secondary systems may be needed. Where a second identical subsystem is required, we have designated it in the table as system (2).

It can be seen that none of the functions reviewed meet all of the suitability criteria. There are, however, 13 that meet four of the five criteria. These control functions should be the priority candidates for standardized controls. The remaining functions are also candidates; however, they might be more appropriately handled as growth functions for the integrated controls.

While we have shown 26 potential candidate avionics control functions for SAICS, we could find no aircraft type that has or is planned to have more than 20 of these functions. For example, a typical military transport aircraft carries most of the redundant communications and some of the redundant navigation equipment, but does not employ IFF interrogators or stores management equipment. The converse is true of, say, an air-superiority fighter.

6.3 PROPOSED FUNCTIONAL GROUPINGS

In Chapter Three we determined that the capabilities of SAICS-like CDUs were such that a second control head would be required to add Group 3 (INS or EW) functions to a Group 1 and 2 (communications, radio navigation, and identification) controller, and that a third controller would be necessary to add mission-unique (Group 4) functions such as stores management. In Chapter Five we determined that a controller for Group 1 alone (communications) did not provide an economic, space, or weight benefit.

We have therefore proposed three variants to our original "trial" function groupings, as shown in Table 6-2. We have organized the groupings by Primary Functions (priority candidates meeting four out of five suitability criteria) and Growth Functions (candidates meeting two or three suitability criteria). Brief discussions of these avionics functions are presented in Sections 6.3.1 through 6.3.3.

6.3.1 Controller for Groups 1 and 2

The controller for Groups 1 and 2 would control 10 standard functions with growth for another 10 or so functions. As pointed out earlier, not all of these functions would be found in all aircraft. Thus, there would be excess capability in some cases. However, the experience gained under the IACS program (adding the doppler control function for $500) and the benefits of standardized hardware, software, firmware, and support compensate for potential penalties. The workload balance for these groups is fairly evenly distributed over the course of the mission.

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Table 6-2. PROPOSED PRIMARY AND GROWTH FUNCTIONS FOR A SAICS		
Groups 1 and 2	Group 3	Group 4
Primary Functions		
TACAN IFF Transponder ILS Crypto (1) Crypto (2) UHF (1) VHF (1) HF (1) ADF (1) Antenna Select	INS EW (1)	SMS
Growth Functions		
IFF Interrogator VHF (2) VOR/DME UHF (2) HF (2) LORAN MLS NATO IFF JTIDS Omega Doppler	EW (2)	New weapons as appropriate -- AMRAAM, ASRAAM, WASP, LANTIRN

6.3.2 Controller for Group 3

The controller for Group 3 would primarily control the INS. Another primary function (or growth function) for the controller would be control of an EW receiver. The workload for the EW receiver is concentrated in the penetration phase of the mission, while control of the INS has a low but constant workload factor over the entire mission, except for take-off and landing.

6.3.3 Controller for Group 4

If a third controller is added, it should address the stores management function of the many new weapon systems entering the fleet. These are not all well defined at this time; however, standard avionics/armament architectures are under development that will make this more predictable in the future.

6.4 CONCLUDING OBSERVATIONS

An avionics subsystem standard with "growth" is not a pure standard. Each growth step introduces a new equipment from a logistics standpoint. Nevertheless, more and more software- and firmware-based "standards" are being introduced into the inventory, with the objective of maintaining flexibility to accommodate new technology.

With a proper acquisition and support strategy, a growth-oriented SAICS can achieve most of the benefits of standardization and still maintain flexibility with respect to technology. Some elements of that strategy should be the following:

- A single agency to oversee the addition of growth functions to a SAICS, to assure that redundant activities are not undertaken
- An architectural philosophy to permit backward compatibility of newer systems with older systems
- A support philosophy for centralized maintenance and configuration control of the units

An overall procurement strategy should be developed to assure that the advantages of large-lot procurement are obtained and that competition is sustained. This latter aspect is important, since many thousands of integrated control units are expected to be purchased, whether standard or not. Among the options for the strategy are:

- MIL-Specification/QPL/QPS approach
- F^3 specification for each Mission Design Series (MDS) procurement
- MIL-PRIME (design guidance) approach
- Reprocurement

Without a centralized acquisition and support strategy, there is a danger of creating a de facto standard that may not meet the full requirements of the Air Force or, worse, proliferation of the numbers of integrated control units in ongoing modifications.

CHAPTER SEVEN

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 SUMMARY

This report has been structured to help Air Force planners make the timely decisions that are required in determining the future of the SAICS program. The state of the art of avionics integrated controls has advanced rapidly during the past ten years, largely because of the development of the MIL-STD-1553 avionics data multiplexer bus and technological breakthroughs in the use of microprocessor controls and displays in an aircraft's cockpit architecture. For the study we developed the four functional control groups shown in Table 7-1. We then performed a criticality-of-failure analysis that related individual and integrated cockpit control failures to the probability of mission failure. Finally, we compared the costs of installing, replacing, or removing individual and integrated controls in the F-111F and four other candidate tactical aircraft.

For the cost analyses, we examined three approaches:

- Approach I - Continue the use of individual control devices for each old and new avionics function.
- Approach II - Use a unique ICS for one or more groups of avionics functions for a given type of aircraft.
- Approach III - For all aircraft types use a SAICS for the functions that are found to be attractive for grouping as in Approach II.

It is evident from our cost-comparison analyses that there are many strategies open to aircraft modification planners when they are reviewing existing and future avionics programs and the costs associated with their cockpit controls. Among these strategies are the following:

- Do nothing to the existing avionics subsystems and accept the fact that they and their controls will become increasingly expensive to support at some time in the future. Add new avionics subsystems and their controls on an individual basis as planned. For the existing avionics, this strategy trades off the increase in future O&S costs against new LCCs and is oriented primarily toward the avionics subsystems rather than controls.

Table 7-1. SAICS TRIAL AVIONICS FUNCTIONAL GROUPS	
Representative Avionics Subsystems	Typical Type of Unit Controlled
Group 1: Communications and Communications Crypto	
UHF	ARC-164
VHF-AM/FM	ARC-186
HF	ARC-190
SEEK TALK	--
UHF/VHF Crypto	KY-58
HF Crypto	KY-75
Group 2: R-NAV and Identification	
UHF/ADF*	OA-8697
TACAN*	ARN-118
VCR/ILS*	ARN-127
ILS*	ARN-108
Antenna Selector	C-4808
IFF Transponder	APX-101
Transponder Crypto	KIT-1A
IFF Interrogator	APX-76
Interrogator Crypto	KIR-1A
GPS	--
MLS*	--
NATO IFF	--
Group 3: INS and EW	
INS	F^3INS
EW Receiver*	ALR-69
Jamming Transmitter*	ALQ-131
Chaff Dispenser	ALE-40
Group 4: Mission-Unique	
Mission Computer*	M-362F
Strike Camera	KB-26A
Weapons Control *	--
NAV/Attack Radar*	APG-63

*In addition to SAICS CDU, would require interaction with other controls or indicators/displays not listed.

- Replace existing avionics subsystems and controls and add new avionics subsystems and their controls by means of separate improvement programs. This strategy makes it easier to obtain program funding, but it is more expensive from the viewpoint of overall aircraft system life expectancy.
- Replace existing avionics subsystems and their controls at the same time that new avionics are added. This strategy makes it difficult to obtain the large amount of investment funds required, but it is less expensive overall than either of the first two strategies.
- Replace existing avionics subsystems and at the same time add new subsystems, combining the control functions of both in one integrated CDU. This strategy is the most expensive initially, but it can easily be the least expensive from an LCC viewpoint.

The cost benefits of using integrated rather than individual controls, as determined in our study, are shown in Table 7-2. The table comments apply to the use of a unique ICS or SAICS for the F-111F separately and for all candidate aircraft to control both existing and planned avionics.

Table 7-2. INTEGRATED-CONTROL COST SAVINGS

Group(s)	F-111F		All Candidate Aircraft	
	Approach II	Approach III	Approach II	Approach III
1	No	No	No	No
1, 2	Yes*	Yes*	Yes*	Yes*
1, 2, 3	Yes**	Yes**	Yes*	Yes*
1, 2, 3, 4	Yes*	Yes*	N/A	N/A

*Provided all planned avionics subsystems are installed.
**Provided all planned avionics subsystems are installed and existing controls are not removed separately.

The greatest benefits to be derived from an integrated control in our candidate aircraft lie in the control of Group 1 and Group 2 functions with a single integrated CDU. However, for Groups 1, 2, and 3 the cost savings may not be as attractive as for Groups 1 and 2, since two CDUs are needed. The economic attractiveness of adding Group 3 functions should therefore be considered on a case-by-case basis. Although there are integrated-CDU cost benefits for control of Group 4 avionics subsystems, additional study on an individual-aircraft basis would be required to identify these benefits since our candidate aircraft have widely varying and evolving avionics architectures today and the details of required integration engineering must be treated on a case-by-case basis.

7.2 CONCLUSIONS

7.2.1 Current Integrated Control Concepts

The concept of using integrated CDUs such as that envisioned for SAICS has already been proven, and production equipment exists. Several of these are adequate to meet current Air Force needs. For the initial installation period assumed in this study (post-1985), a large increase in the number of avionics functions controlled by a SAICS CDU, well beyond those mentioned in this report, is anticipated. It is possible that three or more integrated CDUs will be used in a single operation.

All of the modern integrated systems reviewed have a digital multiplexer bus interface and are of modular design. For flexibility, the later systems also contain a microprocessor in their control heads, which, as in the case of the SRR, relieve the main aircraft computer of some of its bus-control duties if necessary.

Most integrated controls are oriented toward control of CNI functions. In addition, most are mounted in a console readily accessible to the air crew, and none are bigger than the A-10 F^3INS control head. (Exceptions to this are the dual 757/767 units, which are fully integrated into the aircraft avionics architecture and control all phases of flight.) In two-seat aircraft, a second control unit is available to serve as a back-up and to ease cockpit workload.

7.2.2 Failure Criticality

Our calculated probability of mission failure is much lower than that normally to be expected. However, it is noted that an avionics complement includes many more subsystems (e.g., instruments and displays) than those included in our groupings. Further, individual control-head reliabilities are normally higher than those of other avionics LRUs.

The probability of failure when an integrated CDU is being used is lower than when individual controls are being used. However, a back-up CDU significantly lowers the probability of mission failure due to a CDU failure. In the case of a single integrated CDU a reversionary control could also be considered to provide back-up. The addition of a third SAICS-type CDU has little impact on the probability of failure.

Our quantitative findings are considered a worst-case situation. They do not, for example, account for the fact that the integrated controls can be designed such that avionics subsystems continue to operate on the currently selected channel or mode even after a CDU failure. Therefore, a CDU failure may or may not represent a mission failure in a particular operational environment.

7.2.3 *Economic Benefits*

The use of SAICS to control only communications (Group 1) functions does not provide an economic benefit.

The comparison of the F-111F, Approach I versus Approaches II or III, Figure 7-1, shows that the addition of an integrated CDU to control the existing avionics costs more than the replacement of the existing individual controls. However, the integrated CDU hardware has the potential for growth, while the individual control hardware does not. When new avionics are added, the integrated CDU approaches (II and III) exhibit cost savings over Approach I.

For all candidate aircraft, the comparison of Approach I with Approaches II or III (Figure 7-2) illustrates the results of comparing Groups 1 and 2 and Groups 1, 2, and 3. For Groups 1 and 2, Approaches II and III produce cost savings when the post-1985 new avionics are installed. This one-time installation would provide the capability subsequently to remove individual "old" controls as they become superseded since the integrated CDU memory capacity would be available to integrate each individual control function into the CDU at the appropriate time when avionics are updated.

7.2.4 Avionics Architecture and Standardization

The consensus of the technical community is that SAICS should be a growth-oriented architectural approach and, as such, cannot be considered as a true fleet-interchangeable standard equipment. Rather, it would provide for common hardware, standard interfaces, and common development of some software or firmware for functions found within the Air Force. The actual implementation of SAICS in the fleet would probably require tailoring of the growth functions unique to each aircraft type.

The highest proliferation of individual controls appears to be in EW subsystems. Because of the changing nature of the threat, new EW subsystems have been introduced over the years, and their cockpit controls have been located wherever possible. This is especially true in our older candidate aircraft, where cockpit space is very limited. In the case of our F-111F review, for example, we found five different EW controls in four different locations.

Today's method of implementing the bus interfaces required for each avionics subsystem without a standard interface is to develop a separate adapter module. Some advantages of using direct connection are ease of implementation, lower cost, and less complexity, while a disadvantage is the possibility of exhausting the 32 addresses available to a MIL-STD-1553 system for command response.

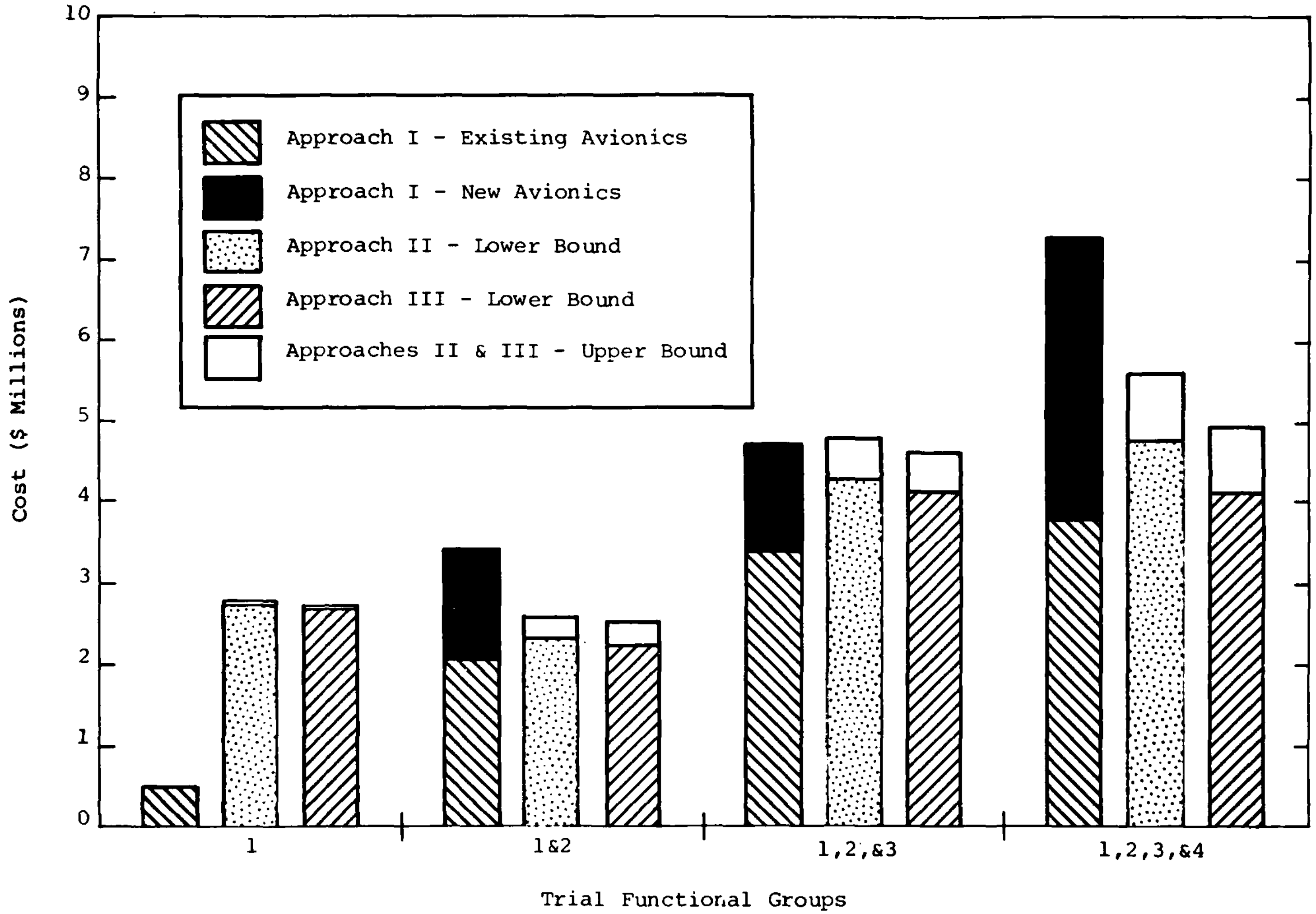

Figure 7-1. F-111F COST COMPARISON FOR APPROACHES I, II, AND III

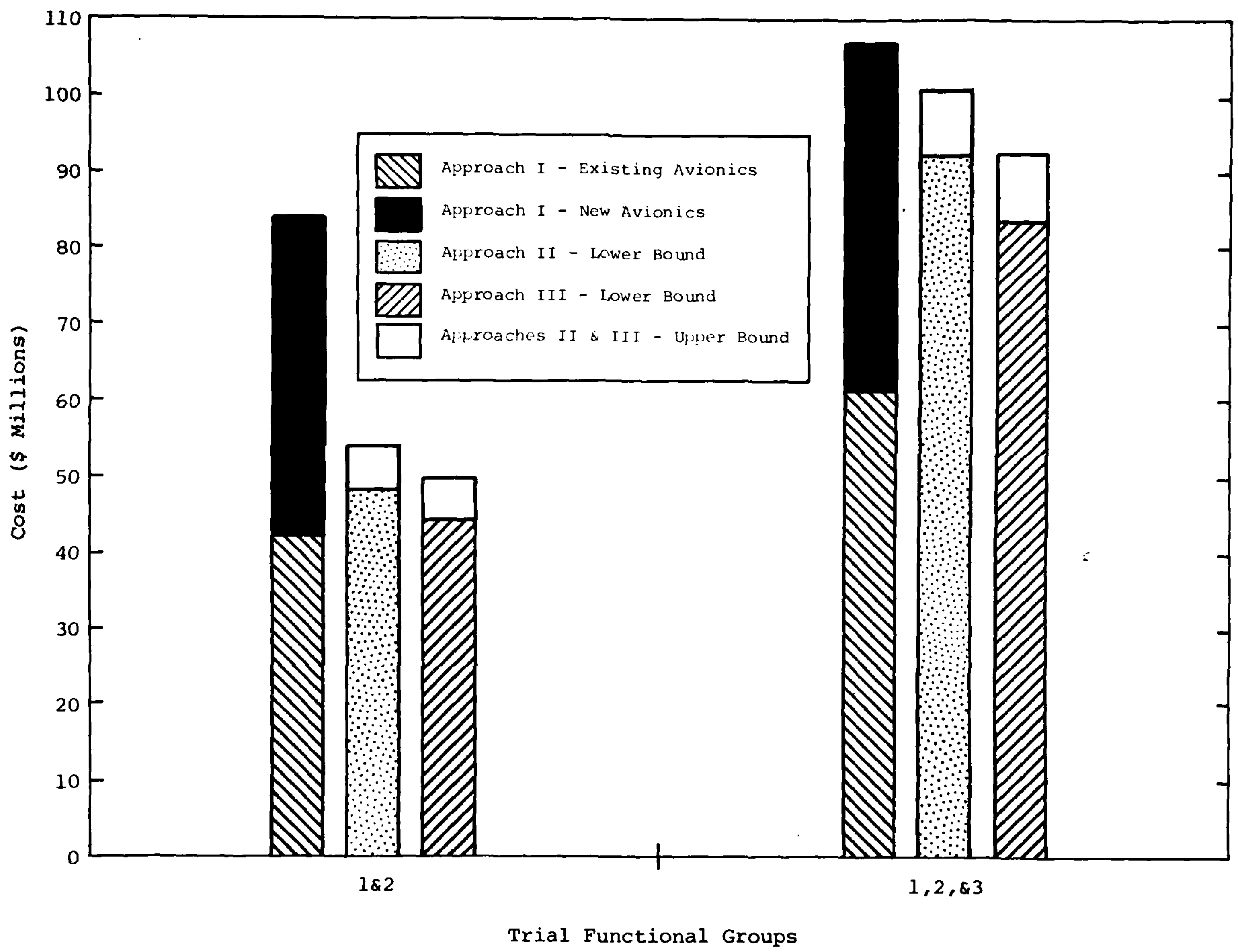

Figure 7-2. ALL CANDIDATE AIRCRAFT COST COMPARISON FOR APPROACHES I, II, AND III

A proliferation of new integrated controls will occur over the next several years, as more Air Force cockpits are updated with SAICS-type CDUs. Plans for the KC-135 and H-X programs, for example, indicate use of dual SAICS-type CDUs (similar to the A-10 F^3INS control) in their integrated cockpits. There are, however, many common attributes among these new controls.

7.3 RECOMMENDATIONS

ARINC Research recommends that Air Force planners responsible for the SAICS effort take the actions described in the following subsections.

7.3.1 Characteristics of SAICS

The current SAICS specification should be revised to include the following characteristics and should be subjected to broad open-forum review by Government and industry representatives:

- Ten standard functions and ten growth functions would be a reasonable characteristic for common SAICS units for multiple aircraft applications.
- A microprocessor should be included in the CDU for flexibility and software partitioning.
- User consensus is that a manual back-up control option for critical avionics functions be provided when SAICS is installed, especially where use of a single control head is envisioned. A relatively simple common manual SAICS back-up (reversionary) control should therefore be prototyped at the time a common SAICS unit is developed. Any additional avionics back-up control can then be hand-tailored to meet unique mission requirements. For SAICS, an automatic means of back-up control, such as having preset back-up frequencies for radios, should also be provided.
- MIL-STD-1553 I/O specifications should be developed; they should include automatic frequency presets for back-up in case of cockpit control failure when adapter modules are being used for avionics that do not have a direct MIL-STD-1553 interface capability.

These recommendations are made within the very limited bounds of the data that we could find relevant to failure of digitally controlled avionics subsystems. With a highly integrated architecture, it is difficult to ascertain the cause of failure and to allocate it to a particular LRU. We strongly recommend that reliability modeling and data-collection techniques be developed to accommodate advanced digital avionics architectures, which will undoubtedly consist of multiple busing structures. This action might properly be undertaken by the Deputy for Avionics Control, since it represents both AFSC and AFLC interests.

7.3.2 Implementation of SAICS

The following actions are recommended:

- The utilization of the SAICS should be required where multiple aircraft are undergoing updates in either Group 1 and 2 avionics subsystems or Group 1, 2, and 3 avionics subsystems. The attention of the Deputy for Avionics Control and other agencies responsible for standardization policy will be necessary. The F-111F aircraft represents an excellent first opportunity for such a program, with design of the SAICS predicated on anticipated future installations in other aircraft.
- An integrated-control software-acquisition strategy should be developed. With the extent of embedded computer systems in today's evolving cockpit architectures, it is evident that strategies are needed for management and standardization of software control algorithms under development or in production hardware. The standardization of MIL-STD-1553 and MIL-STD-1750A interface specifications should be paramount in any strategy investigated. Standardization could be effected in a fashion that would ensure a commonality with both older and newer aircraft.
- An integrated control hardware and software support strategy should be developed. It was not evident from our review that Air Force planning had progressed to a point where future responsibility for support of integrated CDUs was known. Support planning strategies should be developed to ensure implementation of the most cost-effective alternative.

7.3.3 Implementation of Unique Integrated Control Systems (UICSs)

If a decision is made to provide integrated controls on a single-aircraft basis, cost trade-off studies should be conducted to determine how to partition integrated and individually controlled functions, so that cost-effective designs can be undertaken.

There is sufficient consensus on the primary attributes of integrated controls among the developers and users to suggest that a MIL-PRIME specification approach may also be viable. Thus, when tailoring a unique control for a specific aircraft type, some attributes may be common with those used in other aircraft in the fleet. This would be beneficial from a human-factors point of view and, to the extent of hardware or software commonality, would moderate the LCC impact of totally unique systems.

7.3.4 Program of Activities

Our overall proposed program of activities to carry out these recommendations is shown in Figure 7-3. We have added suggested action agencies on the basis of our understanding of the evolving roles of these organizations under AFR 800-28, *Avionics Acquisition and Support*. The figure shows that many of the activities can proceed in parallel, even though the details of

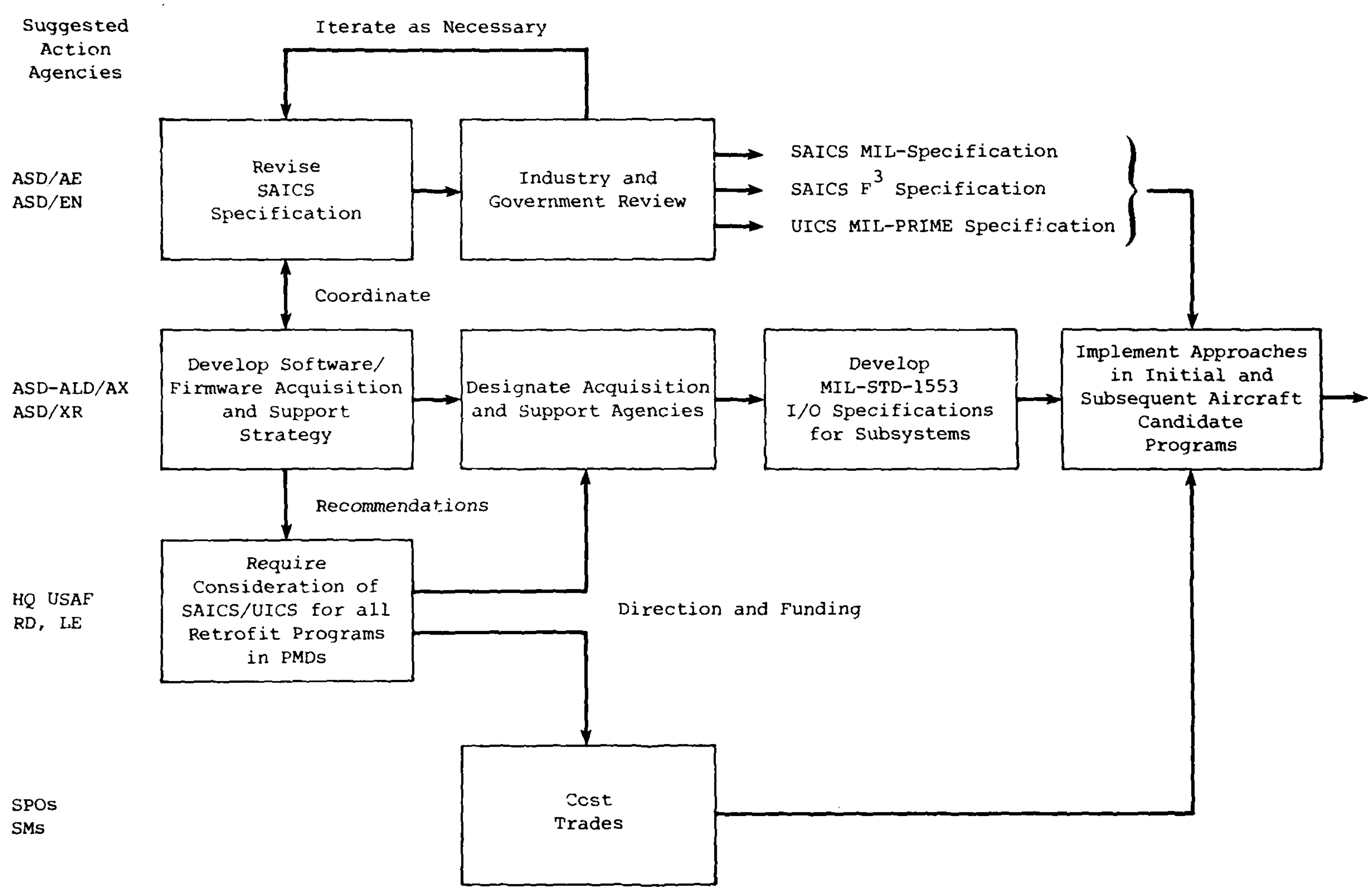

Figure 7-3. RECOMMENDED PROGRAM OF ACTIVITIES

the specification form or acquisition and support strategy are not finalized. Indeed, given the impending numbers of retrofit programs for the mid 1980s, these parallel activities will be required, or many significant opportunities for standardization programs will be missed.

SAICS, of course, is also a candidate as GFE for new aircraft programs; however, the trend for advanced aircraft is toward highly integrated cockpit architectures. SAICS may be highly constraining for the designers of those aircraft. The UICS MIL-PRIME specification approach could serve as a broader design discipline to ensure that Air Force preferences for certain features are communicated and implemented.

APPENDIX A

POINTS OF CONTACT FOR SAICS EFFORT

(Topics discussed are shown in parentheses)

Navy

AIR-533	R. Meyers (PME/F-18 Avionics)
AIR-533	W. King (F-18 C&D/AIDS)
NADC	J. Weikert (LAMPS)
NADC	W. Mulley (AIDS)

Army

AVRADA	H. Gorman (ADAS)
AVRADA	C. Galanti (IACS)
NAVCON	R. Torregrossa (PME)
NAVCON	H. Keister (UH-1H Mod.)

Coast Guard

HC-130 PGM	L/C D. Majerski
HU-25A PGM OFF	L/C J. Hayes (MRS/Falcon Jet)
HH-65A PGM OFF	Cmdr. D. Young (SRR)

ARINC, ARINC Research

Annapolis Office	D. Martinec (ARINC Characteristic 720-1, ARINC Specification 429-4)
WRALC Office	C. Manspeaker/L. Delone (EW)
Santa Ana Office	R. Nelson (GPS Cost)

Headquarters USAF

RDPV	Major L. Dougherty (PME, SAICS)

Headquarters AFLC

LOWW	R. Westbeld (Communications)
LOE	J. Schmidt (Software, etc.)

WRALC

MMIRCA-3	K. Powell (Cost Data)
MMIRC	J. Foxbower (CNI)
MMIRCA	A. Johnson (ARC-164)
MMIRCA	M. Goodroe (SEEK TALK)
MMIRCA	J.V. Thompson (Standardization)
MMRICA	J. Phillips (ARC-190)
MMRICA	J. Kelly (CARA)

SMALC

MMSREM	B.J. Rutledge (F-111 Equip. Spec.)
MMSREM	A. Perez (System Mods)
MMSREM	R. Brown (CCU, NAV Display)

OOALC

MMSRH	R. Butterfield (F-4 Mod.)

OCALC

MMS	L/C C. Miller (KC-135 S.M.)
	J. Partridge (KC-135 FSAS PGM)

Headquarters AFSC

SDNA	Major F. Mayo (PEM 64212)
SDNA	Lt. C. Houston (SAICS 64212/2713)

ASD

ENAID F-15	B. Cook (Instruments)
ENAID CADC	R. Landon
ENAIB KC-135	Major R. Crowsdale (AMHB)
ENAIC C&D	H. Waruszewski (Working Group)
ENAID Inst.	C. Sweet (KC-135, H-X)
ENAIC C&D	G. Morris (KC-135 CDU)
ENACB Comm.	R. Minor (Comm.)
ENACB Comm.	L. Roche (Comm. Radio)
ENECH F-15	R. Pangborn (Human Factors)
ENECH F-16	A. Nagle (Human Factors)
ENECH A-10	R. Schwartz (Human Factors)
ENASD SEAFAC	C. Zelasco (SEAFAC)
ENECH KC-135	D. Gunning (Crew Station Design Facility)
AEAI A-10	Lt. G. Macy (INS CDU)
AEAI A-10	D. Keene (INS CDU)
AEAA SAICS	Major D. Henson (Program Manager)
AEAC CADC	J. Lapp
AEAL Logistics	J. Timmons (A-10 CDU)
AFAL Avionics	R. Morgan (ASID)
AFAL Cockpit	C. Day (ATACS)

AFWAL/FIGR C&D	Dr. J. Reising (Workload/Human Factors)
TAF/EA F-15	W. Soukup (Crew Cockpit)
TAF Lias.	Major R. Andrews (F-111D)
TAF Lias.	L/C C. Pickell (F-4)
XRQH H-X	L/C R. Kalischek (Program Manager)
XRS SAICS	Major G. Schopf (Sponsor)
XYH B-52	W. Wilson (OAS Displays)
XF KC-135	T. Biggs (Avionics - Airlift SPO)
XRH Anal.	G. Quinn (Mission Profiles)
YF F-15	J. Wagner (ICCP Cost)
YFEA F-15	R. Lollar (ICCP Engineering)
YPEA F-16	R. Miller (Instruments)
YPEA F-16	C. Fabian (Crew Cockpit)
AXA Avionics	N. Vivian (SAICS)

<u>ESD</u>

DC	L/C S. Lanier (SEEK TALK)

<u>Collins</u>

CG Work	C. Gunderson
GPS	D. Kothenbeutel
Software	H. Niewsma
Local	T. O'Connor

<u>General Dynamics</u>

F-111 Mods	J. Tiahart (Wash. Marketing)
F-111 PM	W. Shuffler
F-111 Arm.	M. Doyle
F-111 Eng.	E. Kidd

<u>MACAIR</u>

Technology	R. Dieckmann

<u>Sperry</u>

C&D Marketing	J. Haynes (Commercial)
C&D Marketing	T. Donahue (A.F.)
ADAS	W. McConnell/J. Ellis
757/767	L. Bowe (FMCS)

APPENDIX B

MISSION PROFILE SUMMARIES AND RELIABILITY CALCULATION METHODOLOGY

1. MISSION PROFILE SUMMARIES

Tables B-1 through B-5 are summaries of our mission profile investigations. The tables, organized in much the same way as our four trial functional groupings presented in Chapter Three, portray the entire mission profile across the top. The remarks provided on back-up avionics are the result of our discussions with the TAC pilots.

In addition to the mission profiles, mission-performance computer runs were made by ASD/XRH. These computer runs were necessary to establish typical times for the various phases of the mission used in the reliability calculations of Chapter Four. The results of these runs are shown in Table B-6. The 20 minutes provided for loiter (reserve) time was not used in our reliability calculations. The 110 nautical miles (nm) assumed for the F-16A and A-10A A/G penetration and egress distance, and the 186 nm used for the F-111F deep penetration and egress distance are due to the assumed European locations of the bases.

2. RELIABILITY CALCULATION METHODOLOGY

Serial and serial/parallel approaches were used for the individual and integrated control heads. For both approaches, the F-111F Table B-6 mission time of 2.85 hours was divided among the three mission phases: Outbound (1.05 hours), Combat (0.82 hour), and Recovery (0.98 hour). We assumed that the control heads must be operational from the start of the mission to the end of the last usage period. For example, a review of the F-111F EW avionics usage factor (Table B-5) indicates that EW control failure after egress should not affect our calculations.

2.1 Serial Systems

If all of the individual control heads are required for a successful mission, the reliability of the serial system (R_S) is

$$R_s = \prod_{j=1}^{N} (R_j)$$

Table B-1. F-4E A/G MISSION PROFILE

Group Number	Avionics Subsystem	Usage Factors by Mission Phase*											Remarks
		T.O	Cli	Cru	Des	Pen	W.D.	Egr	Cli	Cru	Des	Lnd	
1	ARC-164	1	1	1	1	1	1	1	1	1	1	1	
	KY-28	1	1	1	1	1	1	1	1	1	1	1	
2	ARN-84/118	0	.7	.7	0	0	0	0	0	.7	1	0	
	ARN-127	0	0	0	0	0	0	0	0	0	0	.7	
	MS-35058	1	1	1	1	1	1	1	1	1	1	1	
	IR-2086	0	.1	.1	.8	.8	.8	.8	.8	.8	0	0	
	KY-532/KIT-1A	0	1	1	1	0	0	0	1	1	1	0	
	APX-80/81/KIR-1A	0	0	.2	.2	.2	0	.2	.2	.2	0	0	
	SST-181X/UPN-25	0	0	.2	.2	.2	0	.2	.2	.2	0	0	
3	ASN-63	0	.2	.2	.2	.2	.2	.2	.2	.2	0	0	Back-Up for TACAN.
	APR-38/ALR-46/69	0	.1	.1	.2	.4	.4	.4	.4	.2	.1	0	Would only carry one on a given mission.
	AAQ-8	0	0	0	1	1	1	1	.5	0	0	0	
	ALQ-119/131	0	0	0	0	1	1	1	0	0	0	0	Would only carry one on a given mission.
	ALE-40	0	0	0	0	1	1	1	0	0	0	0	
	AJB-7	0	0	0	0	0	0	0	0	0	0	0	Back-up for Flight Director.
	CPU-82	0	.3	.3	.3	.5	.5	.5	.5	.3	.7	.7	
4	ASN-46	0	0	0	0	.3	.5	.3	0	0	0	0	
	ASQ-91/AJB-7	0	0	0	0	.4	.8	.4	0	0	0	0	
	APQ-120	0	.4	.4	.5	.5	.5	.5	.5	.4	.2	0	
	AVQ-26 (LASER)	0	0	0	0	.1	.1	0	0	0	0	0	
	AVQ-26 (FLIR)	0	0	0	0	.5	.5	.5	0	0	0	0	
	KB-18A/25	0	0	0	0	0	.3	0	0	0	0	0	

*T.O. - Take Off Cli - Climb Cru - Cruise Des - Descend Pen - Penetrate W.D. - Weapons Delivery Egr - Egress Lnd - Land

Table B-2. F-15A A/A MISSION PROFILE

Group Number	Avionics Subsystem	Usage Factors by Mission Phase*									Remarks
		T.O.	Cli	Cru	Des	Combat	Cli	Cru	Des	Lnd	
1	ARC-164	1	1	1	1	1	1	1	1	1	
	KY-28	1	1	1	1	1	1	1	1	1	
2	OA-8639	0	.1	.1	.1	.1	.1	.1	.1	0	Back-up for TACAN.
	ARN-118	0	.5	.5	0	0	0	.5	.5	0	Back-up for ADF.
	ARN-112	0	0	0	0	0	0	0	0	.7	
	C-9011/ARA	1	1	1	1	1	1	1	1	1	
	APX-101/KIT-1A	0	1	1	1	1	1	1	1	0	
	APX-76/KIR-1A	0	.3	.8	.8	0	.3	.3	0	0	
3	ASN-109	0	.2	.2	0	0	.2	.2	.2	0	Back-up for TACAN/ ADF.
	ALR-56	0	.2	.4	.6	.6	.4	.3	0	0	
	ALQ-153/159	0	0	.2	.8	1	.8	.2	0	0	Would not use all on same mission.
	ALQ-119/131/128/135	0	0	.2	.8	1	.8	.2	0	0	
	ALE-45	0	0	0	.1	.5	0	0	0	0	
	ASN-108	0	0	0	0	0	0	0	0	0	Back-up for Flight Director.
	CP-1075/AYK	0	.6	.3	.3	0	.4	.3	.8	.7	
4	CP-1075/AYK	0	.9	.9	.9	.9	.9	.9	.9	0	
	[illegible]WG-20	0	0	.1	1	1	.1	.1	0	0	
	AVQ-20	0	.8	.8	.8	1	.8	.8	.8	0	
	APG-63	0	.1	.3	.9	1	.4	.3	0	0	
	C-8847	0	0	.2	.4	.1	.2	.2	0	0	

*T.O. - Take Off Cru - Cruise Lnd - Land
Cli - Climb Des - Descend

Table B-3. F-16A A/G MISSION PROFILE

Group Number	Avionics Subsystem	Usage Factors by Mission Phase* T.O.	Cli	Cru	Des	Pen	W.D.	Egr	Cli	Cru	Des	Lnd	Remarks
1	ARC-164	1	1	1	1	1	1	1	1	1	1	1	Back-up for VHF.
	ARC-186	1	1	1	1	1	1	1	1	1	1	1	Back-up for UHF.
	KY-58	1	1	1	1	1	1	1	1	1	1	1	
2	ARN-118	0	.7	.7	0	0	0	0	0	.7	1	0	
	ARN-108	0	0	0	0	0	0	0	0	0	0	.7	
	16E1080	1	1	1	1	1	1	1	1	1	1	1	
	APX-101/KIT-1A	0	1	1	1	0	0	0	0	1	1	0	
3	SKN-2416	0	.2	.2	.2	.2	.2	.2	.2	.2	0	0	Back-up for TACAN.
	ALR-46/69	0	.1	.1	.2	.4	.4	.4	.4	.2	.1	0	
	AAR-XX	0	0	0	1	1	1	1	.5	0	0	0	
	ALQ-119/131	0	0	0	0	1	1	1	0	0	0	0	Would not use all on same mission.
	ALE-40	0	0	0	0	1	1	1	0	0	0	0	
	ARU-50	0	0	0	0	0	0	0	0	0	0	0	Back-up for CPU-XXX (Flight Director).
	CPU-XXX	0	.3	.3	.3	.5	.5	.5	.5	.3	.3	.7	
4	M-362F	0	0	0	0	.3	.5	.3	0	0	0	0	
	GD-8080	0	0	0	0	.2	.2	.1	0	0	0	0	
	AVG-HUD	0	0	0	0	.4	.8	.4	0	0	0	0	
	APG-66	0	.4	.4	.5	.5	.5	.5	.5	.4	.2	0	
	HUD Camera	0	0	0	0	0	.3	0	0	0	0	0	

*T.O. - Take Off Cli - Climb Cru - Cruise Des - Descend Pen - Penetrate W.D. - Weapons Delivery Egr - Egress Lnd - Land

Table B-4. F-111F A/G MISSION PROFILE

Group Number	Avionics Subsystem	Usage Factors by Mission Phase*											Remarks
		T.O.	Cli	Cru	Des	Pen	W.D.	Egr	Cli	Cru	Des	Lnd	
1	ARC-164/109	1	1	1	1	1	1	1	1	1	1	1	Back-up for HF.
	ARC-123	1	1	1	1	1	1	1	1	1	1	1	Back-up for UHF.
2	ARA-50	0	.1	.1	.1	.1	.1	.1	.1	.1	.1	0	Back-up for TACAN.
	ARN-84	0	.7	.7	0	0	0	0	0	.7	1	0	Back-up for ADF.
	ARN-58	0	0	0	0	0	0	0	0	0	0	.7	
	C-4808	1	1	1	1	1	1	1	1	1	1	1	
	APX-64/KIT-1A	0	1	1	1	0	0	0	1	1	1	0	
3	AJN-16	0	.2	.2	.2	.2	.2	.2	.2	.2	0	0	Back-up for TACAN/ADF.
	ALR-62	0	.1	.2	.2	.4	.4	.4	.4	.2	.1	0	
	AAR-34	0	0	0	1	1	1	1	.5	0	0	0	
	ALQ-94	0	0	0	0	1	1	1	0	0	0	0	
	ALE-28	0	0	0	0	1	1	1	0	0	0	0	
	A24G-26C	0	0	0	0	0	0	0	0	0	0	0	Back-up for CPU-76.
	CPU-76	0	.3	.3	.3	.5	.5	.5	.5	.3	.7	.7	
4	AYK-6	0	0	0	0	.3	.5	.3	0	0	0	0	
	AJQ-20	0	0	0	0	.3	.5	.3	0	0	0	0	
	AWW-5	0	0	0	0	.3	.5	.3	0	0	0	0	
	ASG-27	0	0	0	0	.4	.8	.4	0	0	0	0	
	APQ-128/146	0	0	0	1	1	1	1	0	0	0	0	
	APQ-144/161	0	.4	.4	.5	.5	.5	.5	.5	.4	.2	0	
	AVQ-26 (LASER)	0	0	0	0	.1	.1	0	0	0	0	0	
	AVQ-26 (FLIR)	0	0	0	0	.5	.5	.5	0	0	0	0	
	KB-18A	0	0	0	0	0	.3	0	0	0	0	0	
	ID-1748/AYK	0	.4	.4	.5	1	1	1	.5	.4	.2	0	
	C8586/AYK	0	.4	.4	.5	1	1	1	.5	.4	.2	0	
	12E44201-807	0	0	0	0	1	1	1	0	0	0	0	

*T.O. - Take Off   Cru - Cruise   Pen - Penetrate   Egr - Egress
Cli - Climb   Des - Descend   W.D. - Weapons Delivery   Lnd - Land

Table B-5. A-10A A/G MISSION PROFILE

Group Number	Avionics Subsystem	Usage Factors by Mission Phase*											Remarks
		T.O.	Cli	Cru	Des	Pen	W.D.	Egr	Cli	Cru	Des	Lnd	
1	ARC-164	1	1	1	1	1	1	1	1	1	1	1	Back-up for VHF.
	ARC-186	1	1	1	1	1	1	1	1	1	1	1	Back-up for UHF.
	KY-28/58	1	1	1	1	1	1	1	1	1	1	1	
2	OA-8697	0	.1	.1	.1	.1	.1	.1	.1	.1	.1	0	Back-up for TACAN.
	ARN-118	0	.7	.7	0	0	0	0	0	.7	1	0	Back-up for ADF.
	ARN-108/127	0	0	0	0	0	0	0	0	0	0	.7	
	160D180340	1	1	1	1	1	1	1	1	1	1	1	
	UPN-25	0	1	1	1	0	0	0	1	1	1	0	
	APX-101/KIT-1A	0	1	1	1	0	0	0	1	1	1	0	
3	F^3INS	0	.2	.2	.2	.2	.2	.2	.2	.2	0	0	Back-up for TACAN/ ADF.
	ALR-46	0	.1	.1	.2	.4	.4	.4	.4	.2	.1	0	
	ALQ-119/131	0	0	0	0	1	1	1	0	0	0	0	Would not use both on the same mission.
	ALE-40	0	0	0	0	1	1	1	0	0	0	0	
	ASN-129	0	0	0	0	0	0	0	0	0	0	0	Back-up for CPU-80.
	CPU-80	0	.3	.3	.3	.5	.5	.5	.5	.3	.7	.7	
4	AWG-ACS	0	0	0	0	.3	.5	.3	0	0	0	0	
	ASG-29	0	0	0	0	.4	.8	.4	0	0	0	0	
	KB-26A	0	0	0	0	0	.3	0	0	0	0	0	
	ACP	0	0	0	0	1	1	1	0	0	0	0	

*T.O. - Take Off　Cru - Cruise　Pen - Penetrate　Egr - Egress
Cli - Climb　Des - Descend　W.D. - Weapons Delivery　Lnd - Land

Table B-6. COMPUTED MISSION PROFILES (INFORMATION PROVIDED BY ASD/XRH)

Mission Phase	F-4E (A/G)		F-15A (A/A)		F-16A (A/G)		F-111F (A/G)		A-10A (A/G)	
	Incremental Time and Distance		Incremental Time and Distance		Incremental Time and Distance		Incremental Time and Distance		Incremental Time and Distance	
	Hours	Nautical Miles	Hours	Nautical Miles	Hours	Nautical Miles	Hours	Nautical Miles	Hours	Nautical Miles
Takeoff	.083	0	.083	0	.083	0	.083	0	.083	0
Climb	.035	18	.142	67	.062	24	.150	65	.144	30
Cruise	.107	51	1.710	858	.024	10	.683	291	.083	21
Descent	.088	31	.167	57	.167	66	.133	44	.083	21
Penetration (A/G)*	.107	54	0	0	.221	110	.367	186	.378	110
Combat (M = .9, 2 sustained turns) (A/A)	N/A	N/A	.015	0	N/A	N/A	N/A	N/A	N/A	N/A
Weapon Delivery (A/G)	.083	0	N/A	N/A	0	0	.083	0	0	0
Egress (A/G)	.107	54	N/A	N/A	.221	110	.367	186	.348	110
Climb	.053	18	.021	9	.023	8	.133	64	.045	9
Cruise	.078	38	1.631	793	.100	34	.567	245	.220	43
Descent	.117	44	.368	179	.167	57	.283	91	.083	21
Reserves										
(Loiter + 5% initial fuel)	.333	0	.333	0	.333	0	.333	0	.333	0
Total (without reserve)	0.848	308	4.137	1,963	1.067	419	2.85	1,172	1.467	365

*Penetration and egress distances computed for assumed bases of operations to assumed target areas.

where

N = number of control heads in series in the system

R_j = reliability of control head j

The probability of mission failure (P_F) is determined by

$$P_F = 1 - R_s$$

An exponential failure rate was assumed; therefore, the control-head reliability (R_j) for a specific mission time usage is

$$R_j = e^{-\lambda_j t_j}$$

where

$\lambda_j = (MTBF_j)^{-1}$ for control head j

t_j = mission usage time for control head j

As an example, we calculate the serial reliability for the first and second groups:

$$R_{SG12} = R_{G2A} \times R_{G2B} \times R_{G2C} \text{.....etc.} \times R_{G1A} \times R_{G1B} \times R_{G1C} \text{.....etc.}$$

where

R_{SG12} = serial system reliability of Group 1 and Group 2 controls

R_{G2A} = reliability of control head G2A unique to Group 2

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.
.
.

R_{G1A} = reliability of control head G1A unique to Group 1

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.
.
.

We calculate the overall serial system reliability for all four groups:

$$R_{SG1234} = R_{SG1} \times R_{SG2} \times R_{SG3} \times R_{SG4}$$

where

R_{SG1234} = serial system reliability of all Group 1, 2, 3 and 4 control heads

R_{SG4} = reliability for controls unique to Group 4

R_{SG3} = reliability for INS and EW avionics control heads in Group 3

R_{SG2} = reliability for R-NAV and ID control heads in Group 2

R_{SG1} = reliability for communications control heads in Group 1

We calculate the probability of mission failure for all four groups:

$$P_{FG1234} = 1 - R_{SG1234}$$

2.2 Serial/Parallel Systems

If only some of the control heads must be operational for a successful mission because there are back-ups or alternate modes of operation, the computations become more complex. Reliability for serial/parallel systems (R_P) was calculated by the equation

$$R_P = \left[\prod_{j=1}^{N} (R_j) \right] \left[\prod_{k=1}^{M} (R_k) \right]$$

where

R_P = serial/parallel system reliability

N = number of control heads in series in the system

R_j = reliability of the serial control head j

M = number of parallel groups of control heads that are serial to the rest of the control heads in the system

R_k = reliability for the k^{th} group of parallel control heads

R_j is computed as shown in the preceding serial section (2.1). The computation of R_k depends on the number of control heads in parallel in subsystem k.

Two of the simpler parallel-control-head cases used in our analysis are (1) one out of two control heads and (2) one out of three control heads.

The equation for calculating the reliability for the first case is

$$R_{P1} = R_{j1} + R_{j2} - R_{j1} R_{j2}$$

where

R_{P1} = parallel case 1 reliability

R_{j1} = reliability of control head based on $MTBF_{j1}$ and usage time t_{j1}

R_{j2} = reliability of control head j2 based on $MTBF_{j2}$ and usage time t_{j2}

The equation for the second case is

$$R_{P2} = R_{j1} + R_{j2} + R_{j3} - R_{j1} R_{j2} - R_{j1} R_{j3} - R_{j2} R_{j3} + R_{j1} R_{j2} R_{j3}$$

where, again,

R_{j1} = reliability of control head j1 based on $MTBF_{j1}$ and usage time t_{j1}

......., etc.

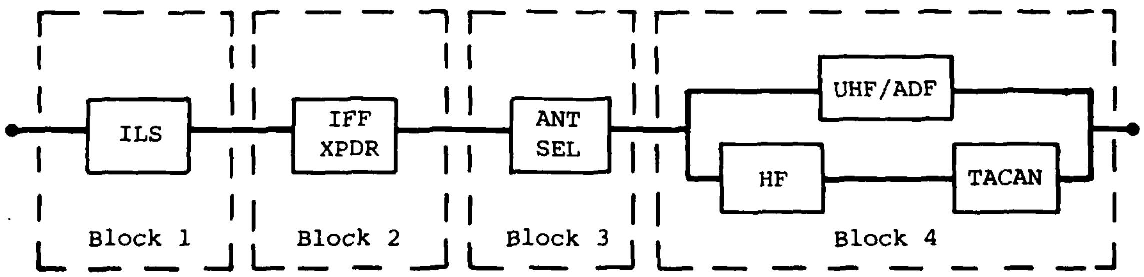
For our individual control-head serial/parallel cases, we made the following assumptions for the F-111F:

- The UHF and UHF/ADF controls are contained in the same head, and this head is a back-up for the HF radio control head.
- The UHF/ADF is always an alternate mode of operation for the TACAN, but the TACAN and UHF/ADF are only alternate modes of operation for the INS during the inbound and recovery mission phases.

2.3 Sample Calculation

For illustration purposes, we now present the Group 1 and 2 system reliability computations for the F-111F.

First, we developed the Group 1 and 2 system reliability diagram:



Blocks 1-4 are in series; therefore, each block's reliability is multiplicative.

As stated above, the operation that describes a serial/parallel system is

$$R_p = \left[\prod_{j=1}^{N} (R_j)\right]\left[\prod_{k=1}^{M} (R_k)\right]$$

where

N = 3 (j=1 for Block 1, j=2 for Block 2, etc.)

M = 1 (k=1 for Block 4)

For this example, the mission time for all Group 1 and 2 avionics is equal to 2.85 hours. The MTBFs of the subsystems involved, as taken from Table 4-1 (Chapter Four), are:

Subsystem	MTBF
UHF	1,700
HF	211
TACAN	8,458
UHF/ADF	1,700
ILS	5,000
IFF XPDR	651
ANT SEL	5,087

Further, $R_p = R_{Block\ 1} \times R_{Block\ 2} \times R_{Block\ 3} \times R_{Block\ 4}$

where

$$R_{Block\ 1} = R_{ILS} = e^{-\left(\frac{2.85}{5,000}\right)} = 0.0004$$

$$R_{Block\ 2} = R_{IFF\ XPDR} = e^{-\left(\frac{2.85}{651}\right)} = 0.9956$$

$$R_{Block\ 3} = R_{ANT\ SEL} = e^{-\left(\frac{2.85}{5,087}\right)} = 0.9994$$

$$R_{Block\ 4} = R_{UHF/ADF} + R_{HF}\ R_{TACAN} - R_{UHF/ADF}\ R_{HF}\ R_{TACAN}$$

Thus

$$R_{Block\ 4} = e^{-\left(\frac{2.85}{1,700}\right)} + e^{-\left(\frac{2.85}{211} + \frac{2.85}{8,458}\right)} - e^{-\left(\frac{2.85}{1,700} + \frac{2.85}{211} + \frac{2.85}{8,458}\right)}$$

$$= 0.9983 + 0.9862 - 0.9846 = 0.9999$$

Therefore

$$R_p = (0.9994)(0.9956)(0.9994)(0.9999) = 0.9944$$

$$P_F = 1 - R_p = 0.0056$$

which is the same value as is shown in the second row of Table 4-3 (Chapter Four, page 4-14).

APPENDIX C

AVSTALL MODEL

1. INTRODUCTION

This appendix describes the avionics installation (AVSTALL) cost model developed by ARINC Research Corporation for application to the Navstar Global Positioning System (GPS). It also shows how we used the model and some of its specific equations to develop costs for the cost comparisons presented in Chapter Five.

The AVSTALL model determines the aircraft-peculiar costs of installing avionics subsystems in military aircraft. It is based on cost estimating relationships (CERs) developed from an analysis of 51 earlier Class V avionics modifications to Air Force aircraft. Although the AVSTALL cost model was developed for the GPS program, it is applicable to a wide range of aircraft modifications involving avionics.

2. MODEL DESCRIPTION

AVSTALL estimates the total investment cost for a Class V aircraft modification by employing a combination of throughputs, special GPS CERs, and basic AVSTALL CERs. Generally, the basic AVSTALL CERs are designed to handle a wider range of aircraft installation types, while the special GPS CERs are applicable primarily to systems similar to GPS. Special GPS CERs are not considered part of the general AVSTALL cost model; therefore, they are not discussed further in this appendix.

Aircraft-peculiar costs such as Group A kits, Group A engineering, modification prototype and testing, and installation labor are estimated by using the basic AVSTALL CERs, which are discussed in detail below. Group B costs, including kits and sustained engineering, are throughputs to AVSTALL.

The data used to develop the basic AVSTALL CERs were normalized to express the costs in the same year's dollars and to adjust Group A average unit kit costs and average unit installation costs for learning-curve effects of using different quantities. The normalized AVSTALL quantity is 250 units, and the normalized base year is 1977.

Group A kit costs and Group A and B kit installation man-hours are determined by AVSTALL in a similar manner. For purposes of illustration, the Group A kit procedure is described here. Group A kit costs can be found by using the CER equations in Table C-1. The following procedures are used:

1. Choose the installation descriptor(s) from Table C-1, Column 1 (e.g., install an LRU or remove a cockpit panel).

2. Determine the number of items (N) affected by the modification process (e.g., install two LRUs).

3. If the modification process is installing an LRU, determine the weight (W) of the LRU.

4. Determine the appropriate aircraft category (e.g., if the avionics is to be installed in an F-111F, choose the "fighter and fighter/bomber" category).

5. On the basis of the chosen aircraft category, select the appropriate AVSTALL coefficient of CER (C) from Columns 3 through 10.

6. Input the values of N, W, and C into the corresponding CER equations in Column 2.

7. Sum the nonzero terms in Column 2, yielding the average Group A kit cost over 250 units.

Once the average kit cost is computed, a learning-curve adjustment can be applied to compute a new average Group A kit cost to match the actual kit quantity. A learning curve of 90 percent is recommended on the basis of guidelines in the NASA Technical Memorandum "Guidelines For Application Of Learning/Cost Improvement Curves," TMX-64968. Similarly, a learning curve of 80 percent is recommended for the installation man-hours.

The cost relationship for Group A engineering is based on the average unit cost of the Group A kit for 250 units. The relationship varies with aircraft type; it is expressed as follows:

Group A Engineering Cost = Constant × Group A Average Unit Cost

where

Constant = 100 for fighters, bombers, and heavy attack aircraft

= 80 for helicopters and medium or large transports

= 70 for light attack aircraft and small transports

= 50 for light observation aircraft

Installation Descriptors, N	CER Equation S	Coefficient of CER, $K Fighter and Fighter/Bomber	Heavy Attack	Light Attack and Observation/Attack	Light Observation	Bomber	Medium-Large Transport	Small Transport	Helicopter
Constant	C	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Mounting Shelf									
Install	$CN^{0.8}$	0.10	0.10	0.10	0.08	0.10	0.10	0.10	0.10
Replace	$CN^{0.8}$	0.10	0.10	0.10	0.05	0.10	0.10	0.10	0.10
Modify	CN	0.05	0.05	0.05	0.02	0.05	0.05	0.05	0.05
LRU									
Install	Eq. 1*	0.04	0.04	0.02	0.015	0.04	0.04	0.04	0.04
Relocate	$CN^{0.8}$	0.20	0.20	0.15	0.10	0.20	0.20	0.15	0.20
Major Cable Run									
Install	$CN^{0.5}$	0.15	0.15	0.10	0.08	0.20	0.20	0.10	0.15
Replace	$CN^{0.8}$	0.15	0.15	0.09	0.08	0.20	0.20	0.10	0.15
Cockpit Panel									
Install	CN	0.20	0.20	0.20	0.10	0.20	0.20	0.20	0.20
Remove	CN	0.10	0.10	0.08	0.04	0.10	0.10	0.10	0.10
Relocate	CN	0.20	0.20	0.15	0.08	0.20	0.20	0.15	0.20
Replace	CN	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Modify	CN	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Antenna Location									
Install	CN	0.60	0.60	0.30	0.20	0.40	0.40	0.40	0.50
Remove	CN	0.10	0.10	0.05	0.04	0.10	0.10	0.07	0.10
Relocate	CN	0.60	0.60	0.30	0.20	0.40	0.40	0.40	0.50
Modify	CN	0.40	0.40	0.40	0.15	0.30	0.30	0.27	0.30

*Equation 1: $CN^{0.6}$ (W/N)

Table C-1. COST ESTIMATING RELATIONSHIP FOR GROUP A AIRCRAFT KIT (1977 DOLLARS, 250-UNIT AVERAGE)

The Group A kit engineering prototype cost equals the average Group B common unit cost (B_{CA}) plus the first unit costs of the aircraft-peculiar Group B (B_{P1}), Group A kit costs (A_1), and installation labor costs (I_1). For our calculations we assumed that $B_{CA} = 0$; thus the estimating equation is

$$\text{Prototype cost} = B_{P1} + A_1 + I_1$$

Group A kit prototype test cost is a function of the Group B average unit cost (B_A) and Group A average unit cost (A_A) for 250 units in FY 1978 dollars. This cost does not include additional testing for new or modified Group B equipment.

Prototype test and kit proof cost is equal to:

$$4\left(B_A^{\ 0.4}\right)\left(A_A^{\ 0.8}\right)$$

Because of the small number of prototypes involved, we did not use the learning curve. The sum of the costs for Group A kits, engineering, prototypes, and testing leads to the total Group A cost estimate. Installation costs equal the installation labor hours, as determined by AVSTALL, multiplied by a labor rate. Group B costs include Group B kits and sustained engineering.

(For further information on AVSTALL, see ARINC Research Publication 1727-04-1-1959, *Avionics Installation (AVSTALL) Cost Model for User Equipment of NAVSTAR Global Positioning System*, June 1979.)

3. USE OF MODEL

We used the AVSTALL cost model to calculate three types of CDU control costs: Group A, Group B, and installation. Group A modification costs comprise aircraft modification kit costs and integration costs. Modification kit costs include the efforts, other than installation labor, to modify the aircraft to accept cabling changes, cockpit panel and console changes, and modifications to allow for control head installation. Integration costs include engineering costs to design the modification kits and other costs needed to develop a prototype and to test the modified installation. Group B kit costs include the control head "black box" procurement or modification, and associated sustained engineering costs. Installation costs include the cost of labor to remove old and install new cabling and controls.

The specific equations we used to calculate these costs are presented in Table C-2. As appropriate to our candidate aircraft, we chose the coefficients in the "fighter and fighter/bomber" category. The quantities used in our analysis are discussed in Chapter Three.

Table C-2. AVSTALL EQUATIONS USED TO CALCULATE CDU GROUP A COSTS AND INSTALLATION HOURS

Installation Descriptor	Group A Costs (A-Kits)			Installation Hours		
	LRU	Cable	Panel	LRU	Cable	Panel
Install	$0.04N^{0.6}\left(\frac{W}{N}\right)$	$0.15N^{0.5}$	0.2N	$8\left(\frac{W}{N}\right)^{0.8}N^{0.8}$	$30N^{0.5}$	$69N^{0.5}$
Remove			0.1N	N	$11N^{0.7}$	N
Relocate	$0.2N^{0.8}$		0.2N	$50N^{0.9}$		$29N^{0.5}$
Replace		$0.15N^{0.8}$	0.01N	3N	$25N^{0.5}$	10N
Modify			0.1N			5N